Ranking of Three Pre-veneered Primary Molar Stainless Steel Crowns on Load to Failure after Dynamic Cyclic Fatigue

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CERTIFICATE OF APPROVAL

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Certificate of Advanced Education in Pediatric Dentistry thesis of

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I. Introduction

For restoration of primary posterior teeth, there are numerous choices available to practitioners, parents, and patients. With current trends in dentistry leading to the demand for better esthetics, manufacturers and laboratories have tried to meet these demands with better composite materials, glass ionomers, and porcelains. The ideal restorative technique would assure strength, durability, esthetics, and efficiency in placement. For extensive decay in posterior primary teeth, the options for restorations are limited to the use of a conventional stainless steel crown (SSC).[1] Usual indications for the use of a SSC are primary teeth that have extensive caries (>3 surfaces), teeth after pulpotomy or pulpectomy, and teeth that are hypoplastic.[2] SSCs have been used successfully for the last 50 years as no other restoration has offered the convenience, monetary value, durability, or reliability that is needed when full coverage is indicated.[1,2]

However, conventional SSCs have fallen out of favor with parents and children due to the lack of esthetic appearance of the crown.[3,4,5] Laboratories have started offering posterior pre-veneered SSCs within the last decade to meet this growing esthetic desire. While this has produced enthusiasm among parents to know that there is an option of an esthetic posterior crown, it also has created cause for concern among restoring dentists questioning the durability and longevity of these esthetic crowns.[6]

The posterior pre-veneered crowns were modeled after the anterior pre-veneered stainless steel crowns. Many Studies have shown the limitations of these anterior crowns to be: fractures; poor fit due to minimal ability to crimp the crowns; and limited crown colors.[7,8] There are *in vivo* studies on the esthetics and longevity of posterior veneered crowns.[6,9] Fuks study on the clinical performance of the esthetic posterior crowns concluded that there were several unfavorable issues. Most notably, the crowns created poor gingival health, were expensive for the patient, and were clinically bulky without a natural appearance.[9] In another study, Ram et al concluded that after 4 years of placement, all esthetic primary molar crowns reviewed had chipping of the veneer and had poor esthetic appearance.[6] These findings for anterior veneer crowns should not be accepted for posterior veneer crowns due the fact that anterior and posterior regions of the mouth have differing biting patterns, wear patterns, surface area, occlusal forces, and overall stresses and functions. Thus, independent studies need to be done to determine the differences in property and function of these new posterior veneer crowns when compared to anterior veneer crowns.

Fatigue plays in an important role in the longevity of dental restorations. The daily activity of mastication creates repetitive sub-threshold stresses to the restorations and ultimately leads to failure. Fatigue, in this instance, is defined as the weakening or failure of material due to stress or strain over a period of time.[10] A common way to gather failure data for a material is to perform a static test that shows failure load.

Cyclic loading, however, is usually responsible for the wearing, chipping, and generalized failing of dental restorative materials.[11,12,13] Therefore, cyclic loading *in vitro* may provide better insight to *in vivo* performance and give more realistic values of sustainable stress. This could also lead to a more conservative lifetime estimate for polymer-based, glass-filled composites.[14,15]

As with many materials used in dentistry, one of the most important factors to success is case selection. Considerations such as occlusion (posterior crossbites), bruxism (flat occlusion), and type of diet (hard versus soft foods) all have to be taken into account when placing pre-veneered SSCs. These pre-veneered crowns are thicker than the conventional SSCs with anatomy that might not fit well with pre-existing dentition.[21,22] Occlusal interferences may also cause a crack to form and when combined with the wet environment of the oral cavity, this can weaken the veneer laminate through propagation of the crack due to hydraulic pressure and ultimately cause premature esthetic failure.[23]

Presently there are few *in vitro* studies on the durability of primary posterior pre-veneered SSCs. With the increase in demand for esthetic dentistry, it would be helpful to provide patients, parents, and practitioners with evidence based knowledge of the performance of pre-veneered SSCs. The aim of this study is to rank 3 commercially available posterior pre-veneered SSCs in the order of load to esthetic failure after a simulated year of dynamic cyclic fatigue.

II. Method and Materials

A total of 53, size #4, primary lower left second molar, pre-veneered stainless steel crowns were obtained from 3 different manufacturers. The crowns tested were from Cheng Crowns^{TM} (Peter Cheng Orthodontic Laboratory, Drexel Hill, PA) n=16, Kinder Krowns^{TM} (Mayckin Dental Studio, Minneapolis, MN), n=21, and NuSmile^{TM} Crowns (Orthodontic Technologies Inc., Houston, TX), n=16.

A Proto-Tech Fatigue Cycler (OHSU, OR) and a universal testing machine (QTEST, SINTECH, MTS System Corporation, NC) were used to fatigue the crowns and to perform load to failure testing, respecitively. (Fig. 1) The fatigue machine has 3 independent pistons that allow 3 samples to run simultaneously. (Fig. 2) Calibration of the fatigue machine was done by using the calibration software in the fatigue program and then verified using a twenty-five pound weight. Fatigue loading was delivered by a custom made rounded chisel indenter with the axial load on the maximum convexity of the buccal cusp of the veneered crowns. (Fig. 3)

Steel dies were milled into a shape similar to that of a prepped tooth but slightly smaller. This would allow for a passive fit of the crowns, which was recommended by the manufacturers to prevent additional stress on their veneers. (Fig. 5) The dies were welded onto a steel plate that had been secured on the mounting aluminum platform. (Fig. 4) This was done to minimize creep while the study samples were undergoing fatigue. Each crown was examined for cracks or imperfections in the veneer and veneer thickness randomly measured for 15 crowns at the maximum convexity on the buccal cusp with a Boley gauge. Each crown was cemented to the die using glass ionomer cement, (Ketac, 3M ESPE, St. Paul, MN) which was mixed for 10 seconds per manufacturers' recommendation. The blunted chisel attached to the piston of the fatigue machine was then place on top of a piece of steel which sat over the occlusal surface of the crowns. This piece of steel was used to prevent tipping of the crown during the 7 minutes needed for the cement to set. (Fig. 6)

Each crown was then subjected to the same parameters while undergoing a years worth of fatigue. Parameters were determined using data from other research studies regarding the number of cycles and bite force to be used. The cycles calculated for one year were 657,000 cycles (1800 cycle/day x 365 days) while the bite force of 265N was used (an average of maximum biting force of children between the age of 3-8 years).[16,17,18,19] Parameters of 666,666 cycles, 4 Hz, and 265 N ±20 N (approximately 27 kg ±2 kg) were used for each sample crown.

After cycling of each crown was completed, the chisel placement on the crown was marked with a permanent pen. This allowed for correct placement of the chisel in the universal testing machine. The universal testing machine used a crosshead speed of 0.01 in/min until there was failure of the veneer. The point of failure was detected by Test Works QT version 3.1 and was confirmed by visual observation of failure. Visual failure was defined as the point at which any portion of the veneer delaminated from the SSC, as this would also indicate clinical esthetic failure. The increase in load values was recorded continuously in kilograms (kg) starting at 0 kg by Test Works QT version 3.1 with the use a Gateway E4200 computer. (Fig. 7)

After the load to failure of each crown was recorded, each crown was individually removed off the die and replaced with new crowns onto the same 3 dies. Care was taken to rotate the three tested crowns (NuSmile, Cheng, Kinder) to a different piston. This was done to help standardize chisel and piston differences. With the load at failure for each crown recorded, both a one-way analysis of variance (ANOVA) and a Scheffe's post hoc comparison were used to analyze significant differences between each of the 3 different commercially available crowns.

III. Results

The mean load to failure for the 48 crown samples after a year of fatigue (16 from each manufacturer) are shown in Table 1. (Appendix A, B, C) ANOVA indicated a significant difference when comparing the load to failure of the 16 samples, (P<.0001). (Fig. 8) Scheffe's Post hoc comparison demonstrated that the NuSmile crowns required significantly more force to delaminate the veneer from the SSC than the Cheng or Kinder crowns, $\alpha = 0.05$. (mean NuSmile – 119.5 N, mean for Cheng – 66.6 N, mean for Kinder – 81.15 N) The Cheng crowns, on average, required the least amount of force to cause esthetic failure, but this was not significantly different from the Kinder crowns. (Appendix D, E)

IV. Discussion

Marked differences were found between the 3 pre-veneered crowns statistically and also as seen by the naked eye. (Fig. 9, 10, 11) The shade of the crowns, the thickness of the veneer, the mode of adherence of the veneer to the substructure, and the anatomy of the occlusal surface, and the total area that the veneer covers are distinctive from one group of crowns to the next. The Cheng crowns have more intricate occlusal anatomy, more bulbous cusps, and more surface are veneer than Kinder and NuSmile crowns. The mode of adherence of the veneer is distinctly different between the 3 groups with the use of a mesh work, rough coated gold, punching holes into the crown. With these differences, the expectation would be that the crowns would perform differently under the same stress.

This study expands upon research performed by James (2007) by including a fatigue component and then testing load to failure. This will help clarify the reason for the failure of these crowns clinically. The results of the current research is consistent with the James findings.[20]

Cheng crowns displayed more intricate anatomy with distinctive cusps and well defined grooves when compared to NuSmile or Kinder crowns. It withstood the least amount of load before failure. This may be due to the more bulbous anatomy of the veneer and the overall surface area that the veneer. In contrast, NuSmile crowns have the least amount of occlusal anatomy and the thickest veneer. NuSmile crowns were 0.4 mm thicker than the Cheng and Kinder crowns, which may have enabled it to require the most amount of load before failure. Factors such as anatomy and thickness would be more significant in a clinical situation than a laboratory setting due to the fact that in vitro studies usually test certain points such as maximum convexity of the crown versus overall stress. Therefore, our results are conservative indicators on the performance of these crowns.

Fatigue also causes a process involving nucleation, propagation, and coalescence of cracks. Crack nucleation occurs in regions of stress concentration such as scratches, grain boundaries on the surface, or voids in the interior. Fatigue testing induced by cyclic loading of an indenter into the surface of a material causes tensile stresses at the contact edges, which can lead to crack formation.[24]

Indentation by blunt indenters is considered to be a more realistic loading mode, in that it incorporates compressive stresses as well as tensile stresses in propagating the crack.[25] Thus it is reasonable to think that the pre-veneer SSCs, after undergoing a year of fatigue, would experience crack nucleation which would ultimately influence the amount of load that is necessary to delaminate the veneer. When comparing this study to that of James, the rankings for the same 3 commercially available crowns were identical in respect to load to failure.[20] This finding would indicate that fatigue has minor influences on the 3 different commercial crowns in a similar manner.

It was interesting to note that 5 Kinder Krowns' veneers fractured at initial onset of fatigue or within minimal cycles. This data was excluded in the statistical analysis because they failed to survive the fatigue cycle. Some reasons of why this could have occurred include chisel placement, pre-existing fractures, or internal flaws in the crowns. The hypothesized reason for this instant fracture may be the method used to adhere the veneer to the conventional SSC. Kinder crowns, unlike Cheng and NuSmile crowns, had minute holes (similar to drains of a colander) prior to veneering. (Fig. 12) This is assumed to be done for added retention. The holes punched into the SSC could have compromised the substructure, thus resulting in premature esthetic fracture. The holes in the substructure can act as stress riser and weaken the overall strength of the veneer crown.

In the study done by Ram, et al, regarding the long term clinical performance of esthetic primary molar crowns, it was not noted if the crowns were crimped before placement in the mouth.[6] This is an important factor as it can influence the original integrity of the veneer to the crown. The veneer is designed to adhere to the substructure, i.e. the crown. With crimping, the substructure is changed, and this will the veneer. The manufacturers' recommendation is to passively fit the crowns to the tooth to prevent stress to the veneer. But this poses an additional the problem of poor adaptation, and could lead to poor gingival health, which had been reported by Rams, et al, in their research regarding the long term performance of esthetic molar crowns.[6]

As with many studies, our findings lead to more questions than answers. The oral cavity is quite a unique environment with many factors that may contribute to material failure. This creates considerable challenge when designing an in vitro study. Future studies should try to mimic the oral cavity by adding in factors such as thermocycling, a wet environment, lateral forces, crimping considerations, and fatigue to failure of the crowns.

With the advancement of the scanning electron microscope (SEM), there could be further evaluations regarding the mode of failure for these pre-veneered SSCs. Specifically, SEMs would be used to determine if failure was due to tension-compression fractures or due to overload fractures. Additionally, the use of acoustic emissions could help link the time frame from the first initial crack heard to the time of esthetic failure. Any finding can greatly increase the success rate of these crowns.

V. Conclusion

NuSmile pre-veneered posterior stainless steel crowns requires significantly more load before failure after a year of dynamic cyclic fatigue than Cheng or Kinder crowns. Fatigue can cause material degradation but is not considered to a main contributing factor for failure of these pre-veneered SSCs. The data supports that after a year of fatigue none of the crowns delaminated and the peak of load to failure is what ultimately causes the crowns to have esthetic failure.

VI. Abstract

Purpose: The aim of this study is to rank 3 commercially available posterior pre-veneered SSCs in the order of load to esthetic failure after a simulated year of dynamic cyclic fatigue.

Method: 16 crowns were used from 2 manufacturers and 21 crowns from another manufacturer were used. The 3 different laboratories: Cheng Crowns (Peter Cheng Orthodontic Laboratory); Kinder Krowns (Mayclin Dental Studio Inc); NuSmile Crowns (Orthodontic Technologies, Inc) were used for a total of 53 crowns. Each crown was cemented on a steel die that was welded to a steel plate which was mounted onto an aluminum platform. Each crown underwent a year worth (666,666 cycles) of dynamic cyclic fatigue at an average physiologic load of 265N using the Proto-Tech Fatigue Cycler. Post-fatigue crowns were then placed into a universal testing machine and a vertical force was applied, with a crosshead speed of 0.01mm/minute, to the veneered buccal cusp of the crown until the veneer fractured and delaminated from the stainless steel crown.

Result: The mean load required to cause the esthetic failure was: NuSmile (119.5 ± 16.04 Kg), Cheng (66.6 ± 28 Kg), Kinder Krowns (81.15 ± 21.91 Kg). Analysis of variance (ANOVA) indicated a significant difference between the groups at $P<0.0001$. Scheffe's Post hoc comparison demonstrated that the NuSmile crowns required significantly more

force to delaminate the veneer from the SSC than the Cheng or Kinder crowns, α = 0.05. No crowns broke while undergoing fatigue for the determined number of cycles.

Conclusion: NuSmile pre-veneered posterior stainless steel crowns requires significantly more load before failure after a year of dynamic cyclic fatigue than Cheng or Kinder crowns. The data supports that after a year of fatigue none of the crowns delaminated and the peak of load to failure is what ultimately causes the crowns to have esthetic failure.

VIII. References

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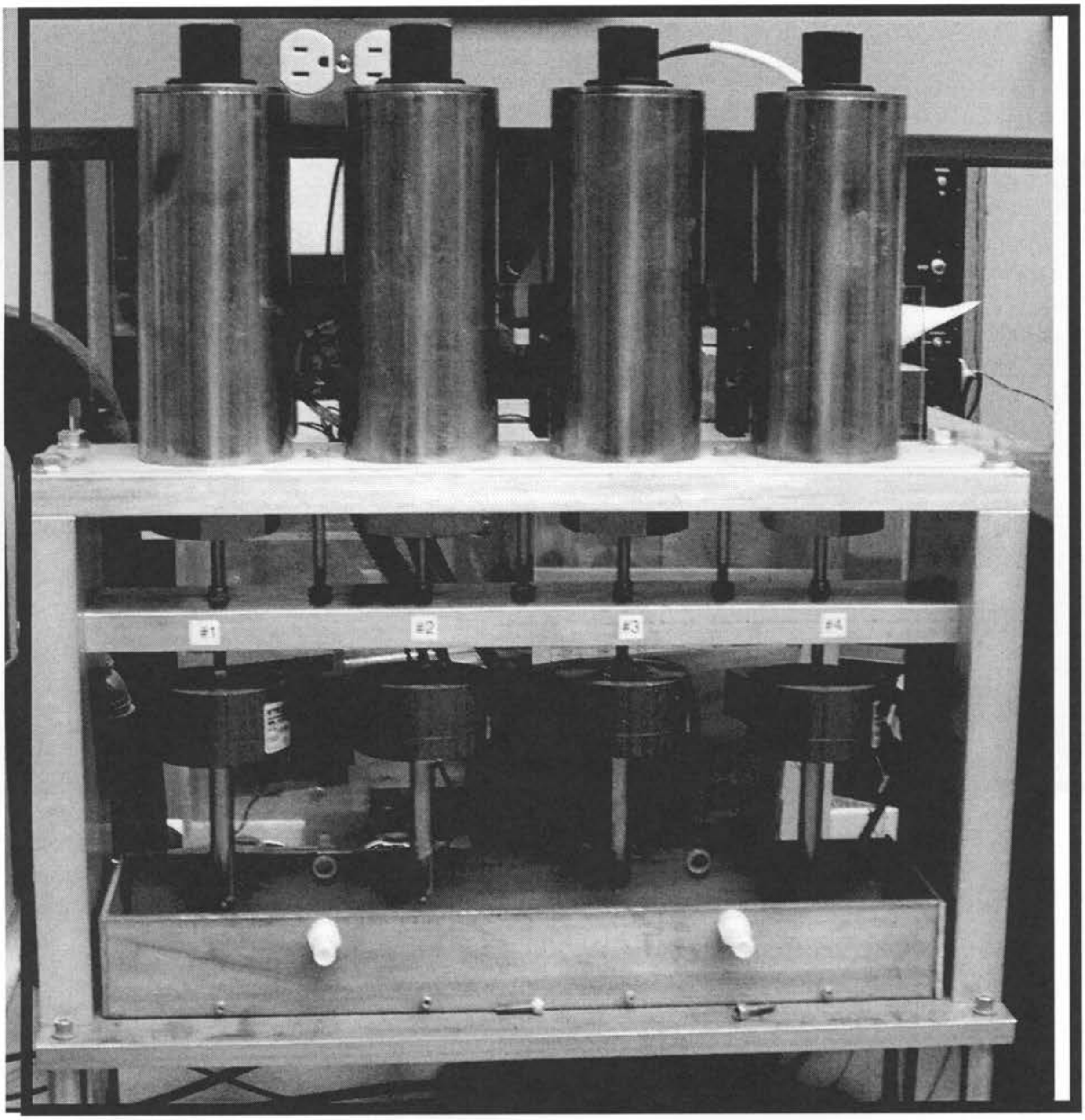


Figure 1. Proto-Tech Fatigue Cycler (OHSU)

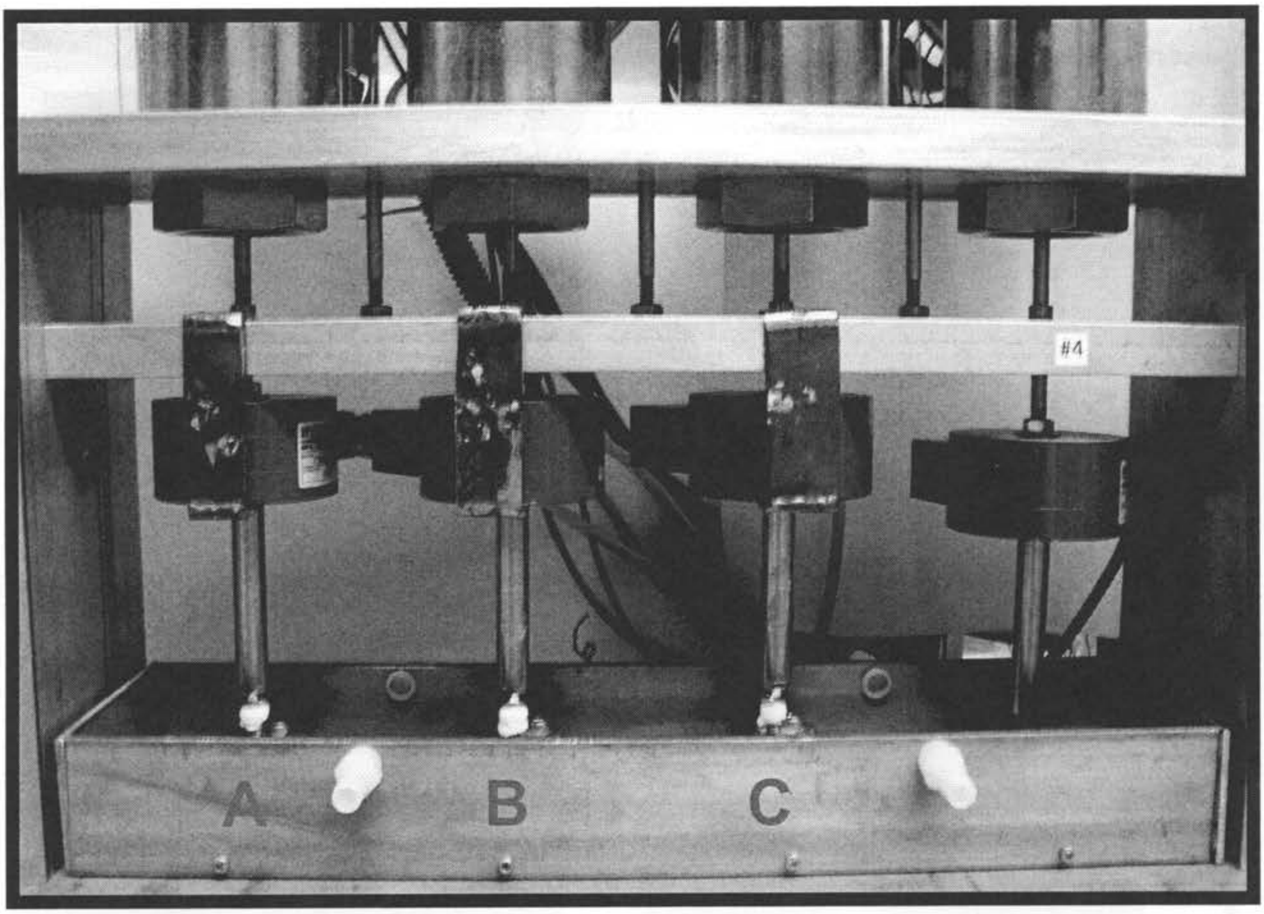


Figure 2. Pistons A, B, C with crowns mounted. Far-Right piston not used.

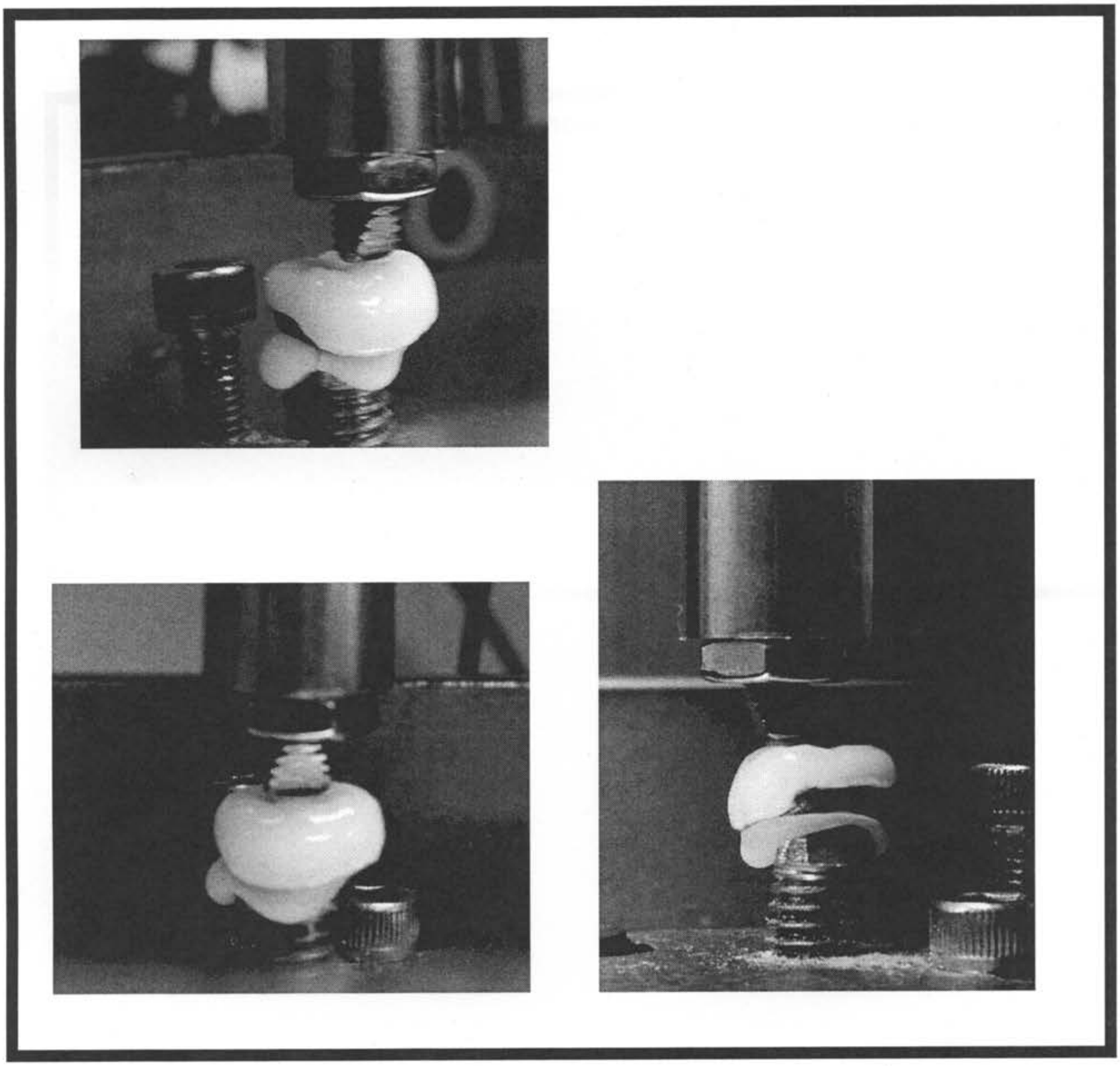


Figure 3. Chisel indenter on the maximum convexity of the buccal cusp of the veneered crowns.

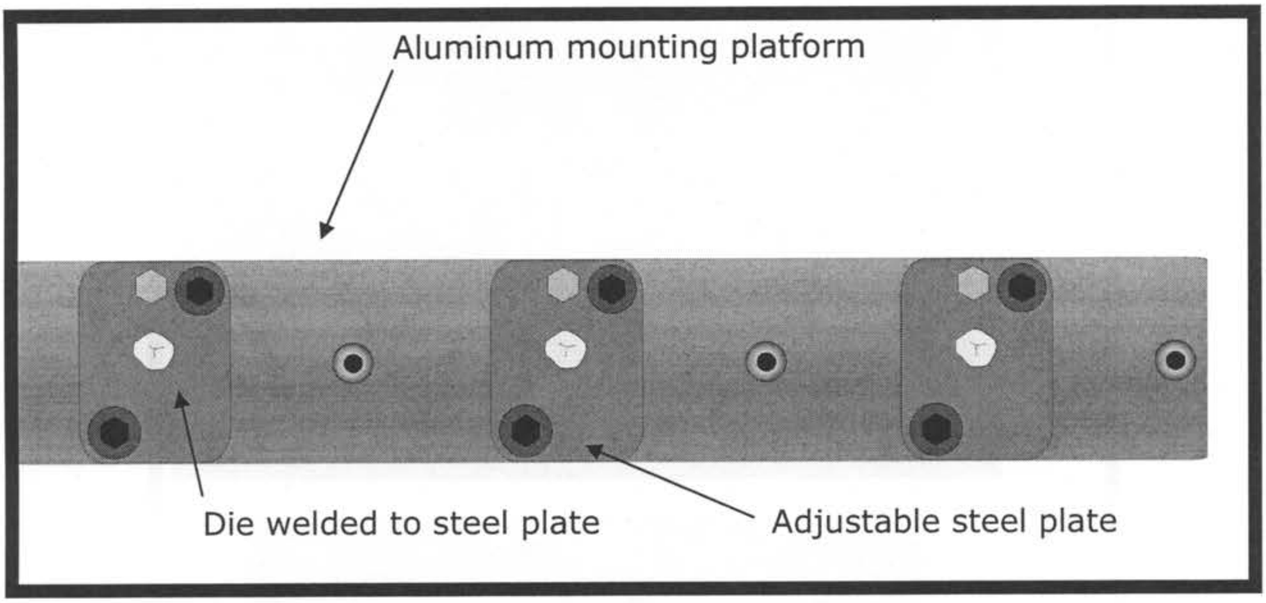


Figure 4. Mounting platform.

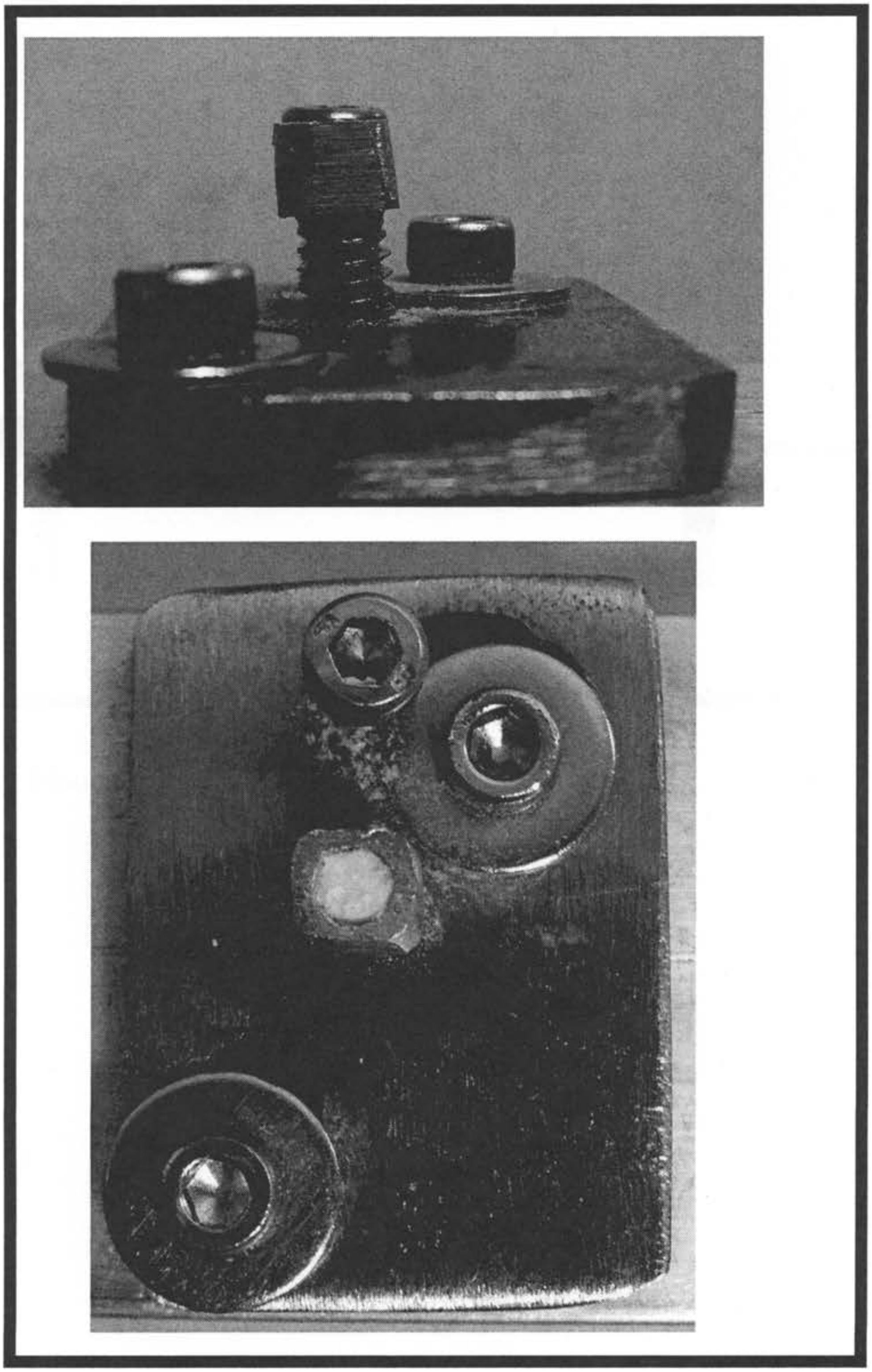


Figure 5. Steel dies.

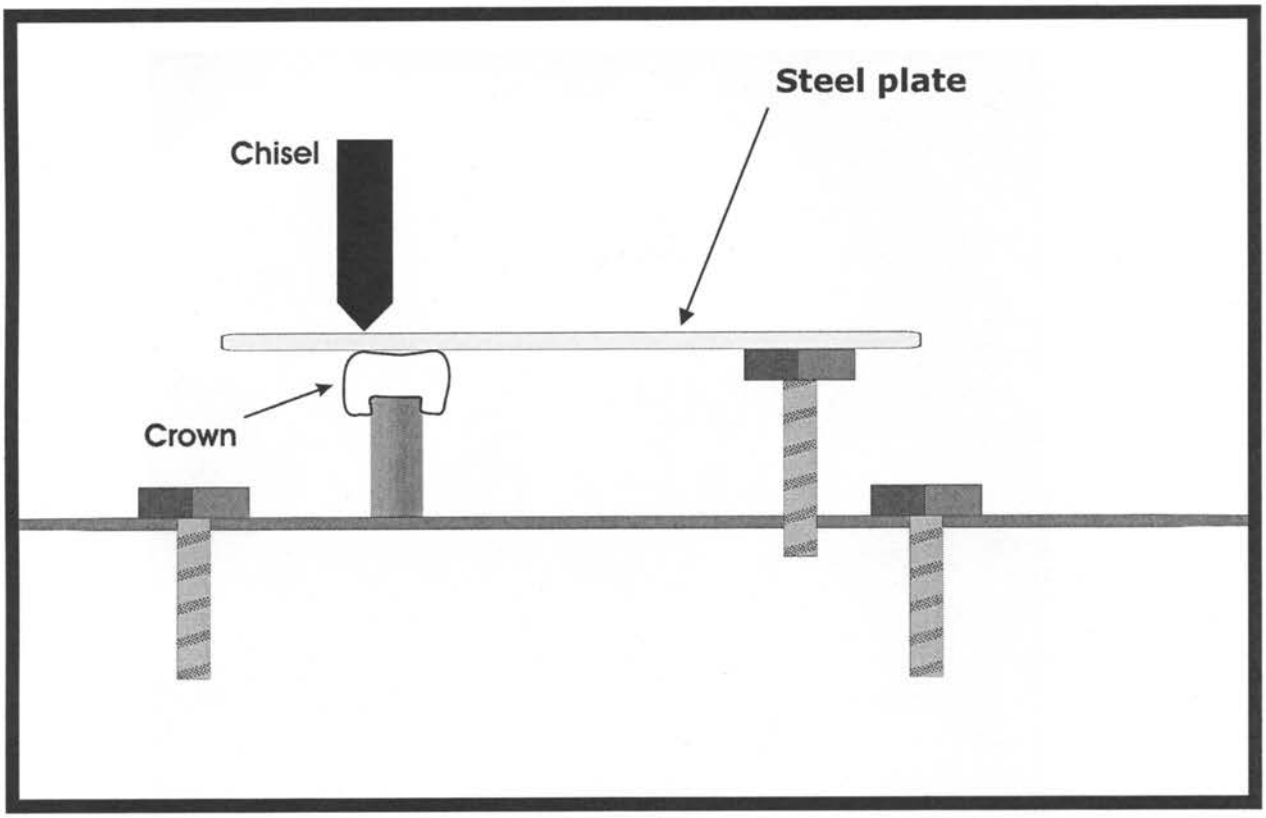


Figure 6. Mounting Profile.

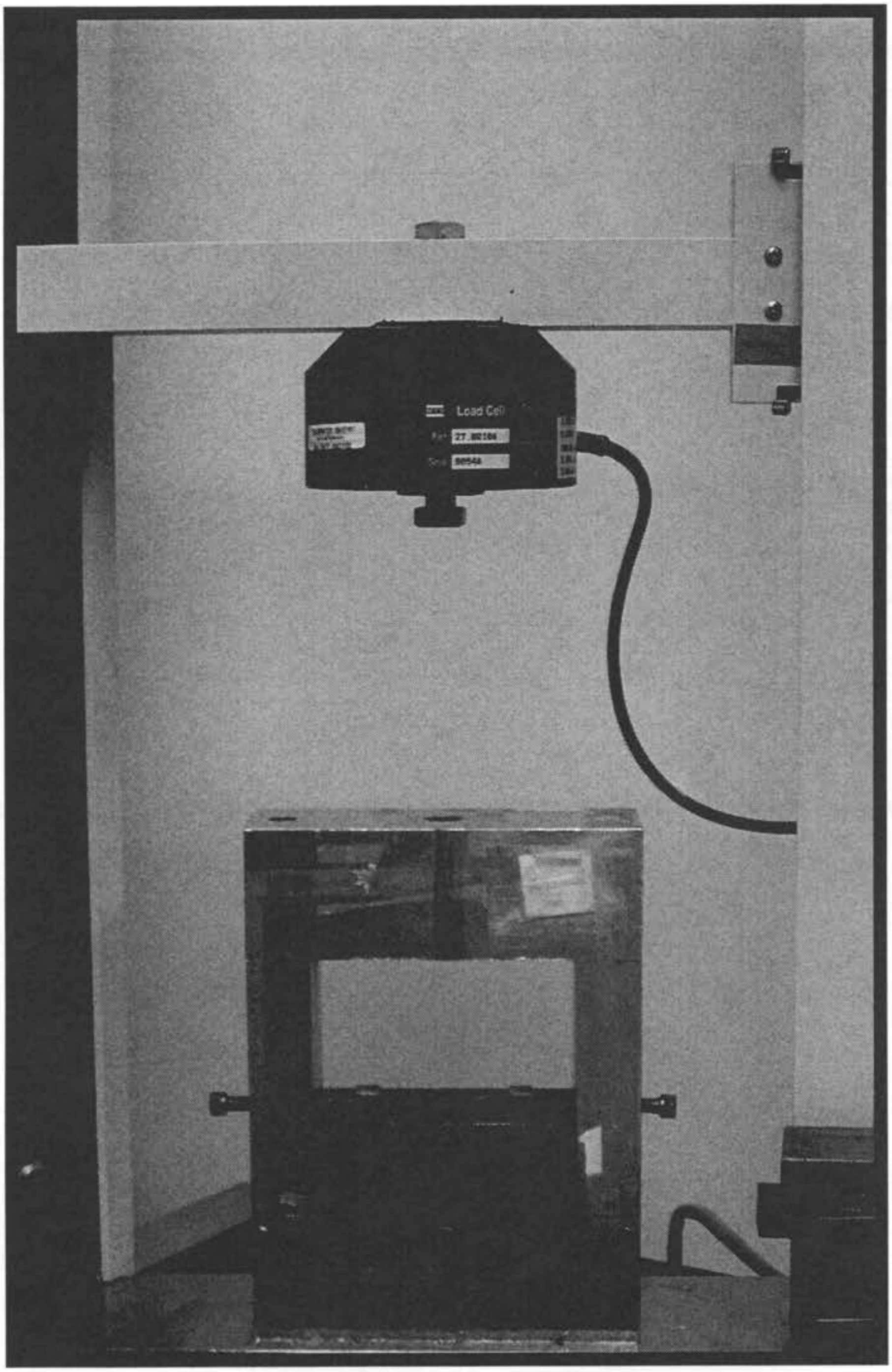
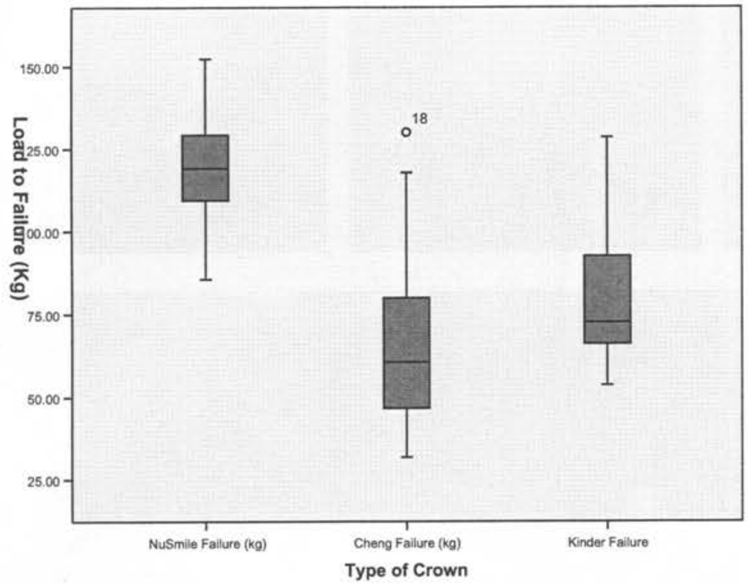


Figure 7. Universal testing machine (QTEST, SINTECH)



Confidence Intervals

NuSmile: (110.8,127.9)

Cheng: (51.68, 81.52)

Kinder: (69.47, 92.82)

Note: Overlap of confidence interval between Cheng and Kinder. The medians are different for the 3 types of crowns and there appears to be a difference in strength between the crowns.

Figure 8. 3-way Box Plot

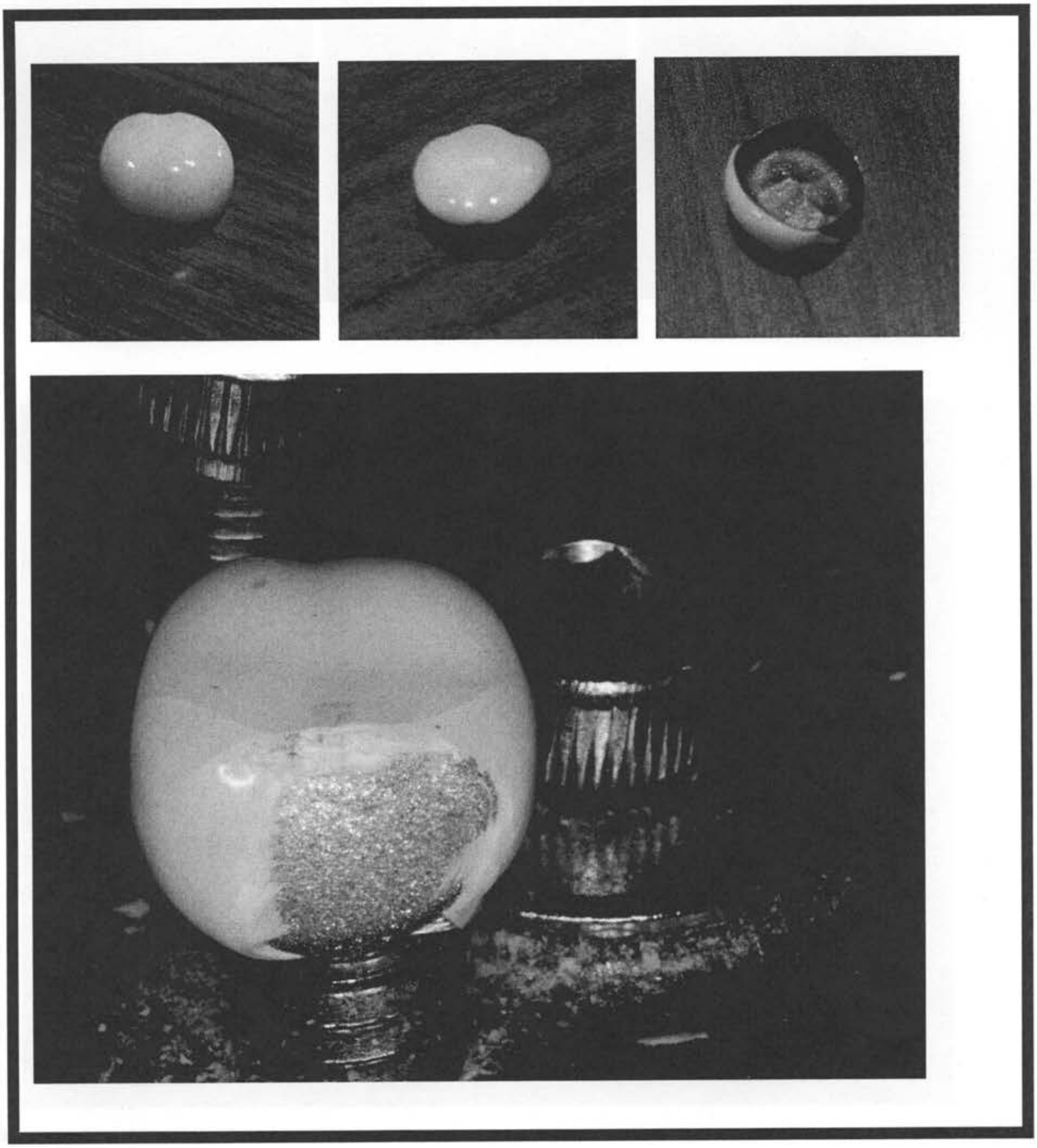


Figure 9. NuSmile Crown

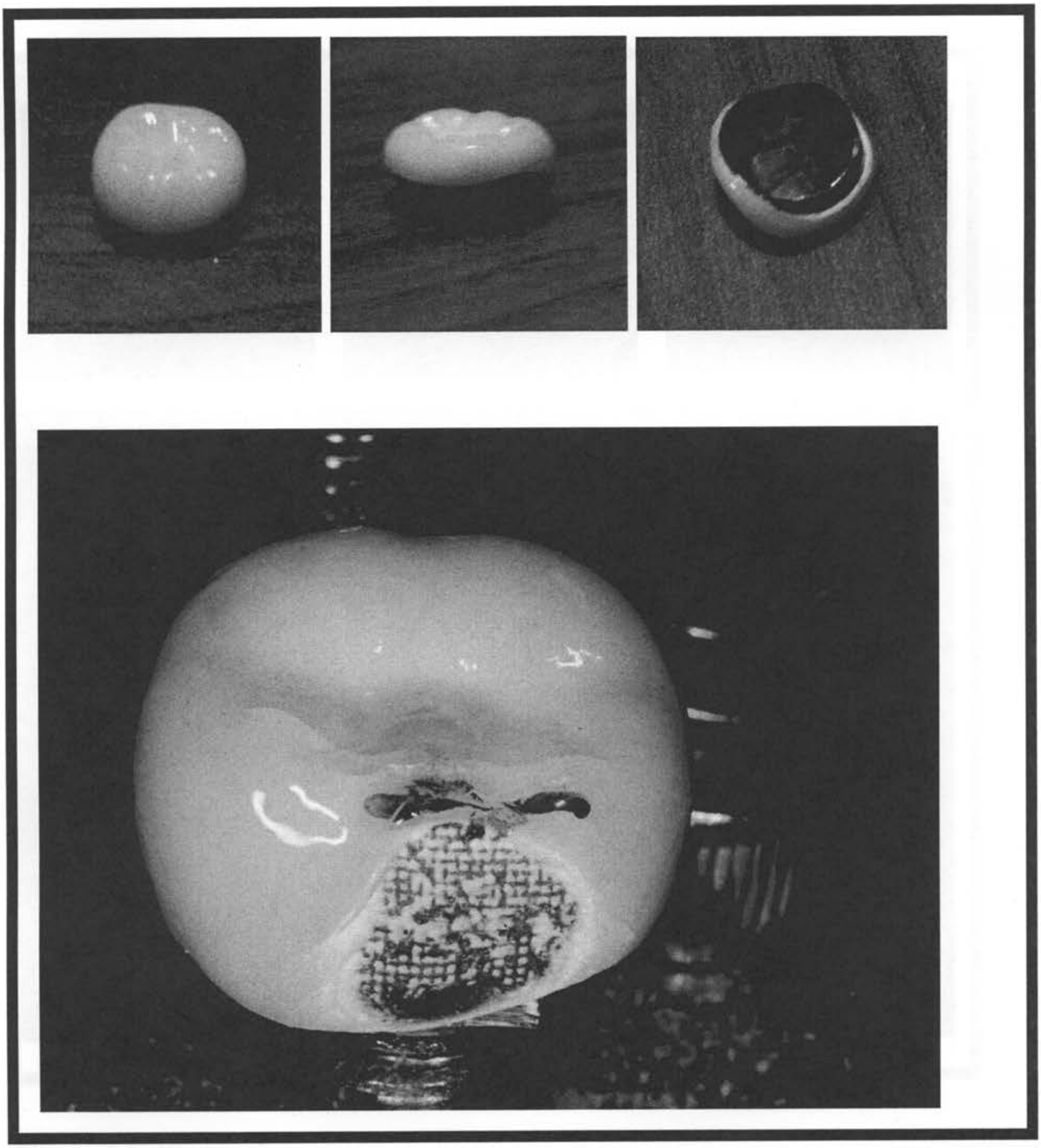


Figure 10. Cheng Crown

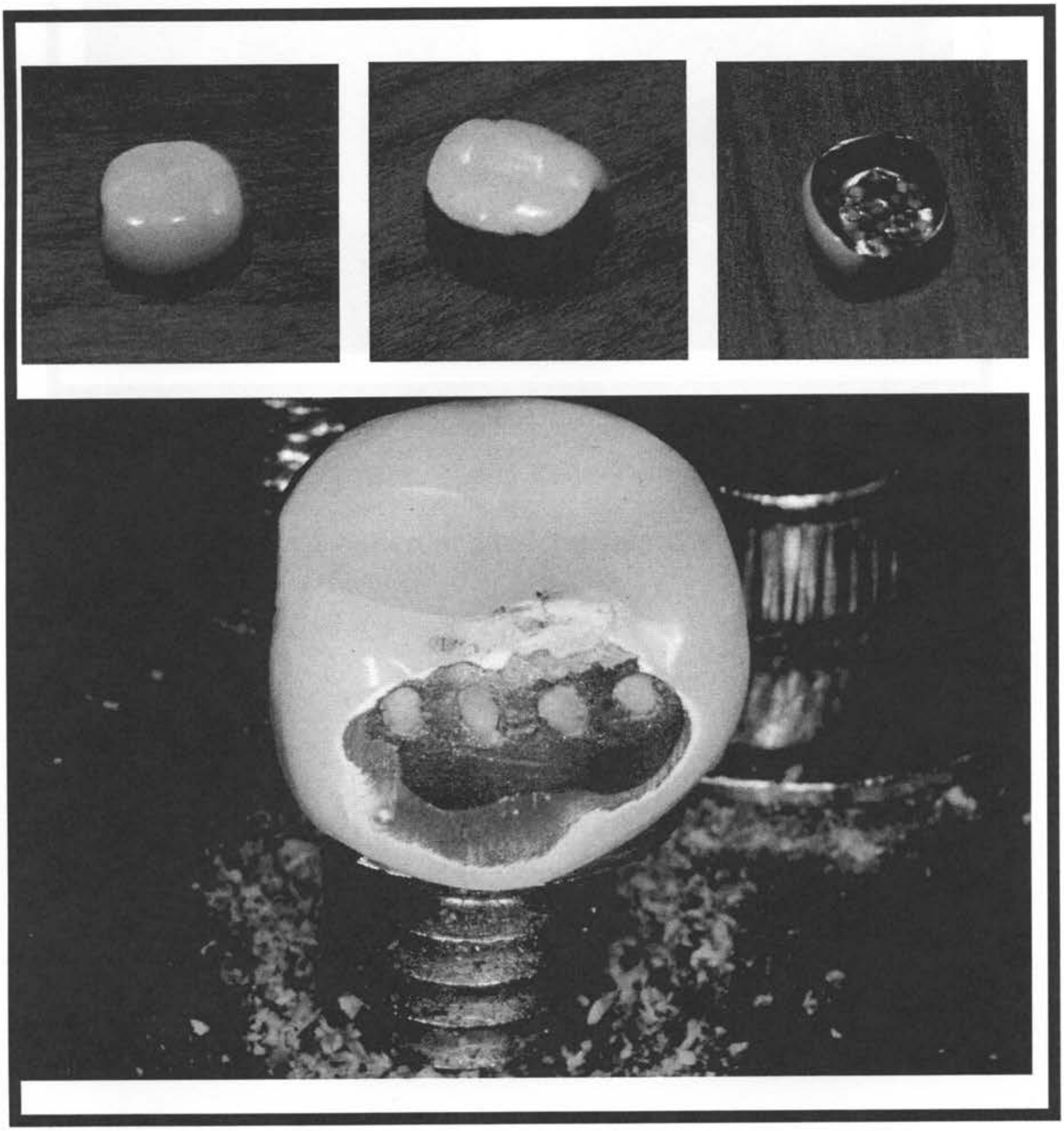


Figure 11. Kinder Crown

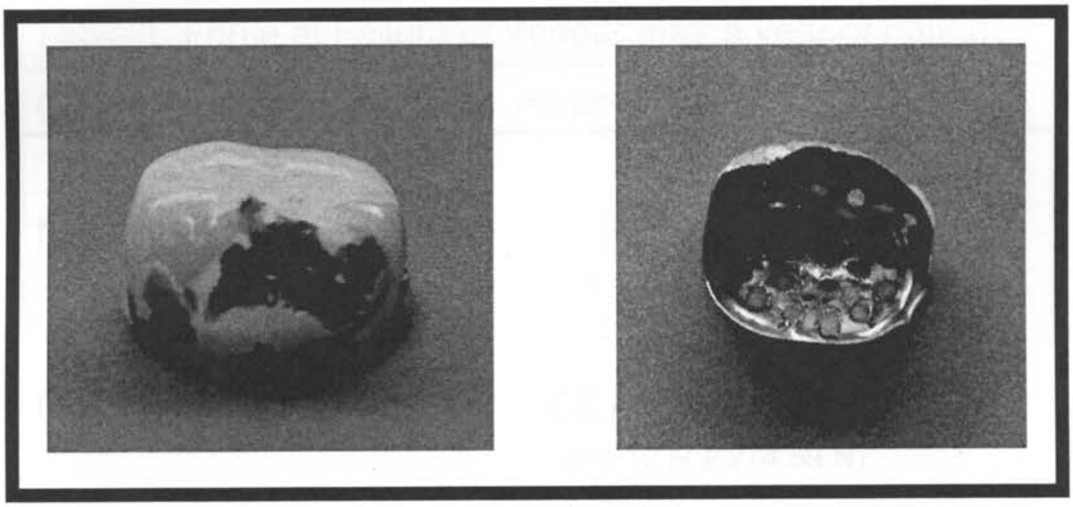


Figure 12. Kinder crowns. (Left) Veneer delaminated from the SSC. (Right) Adherence mechanism shown.

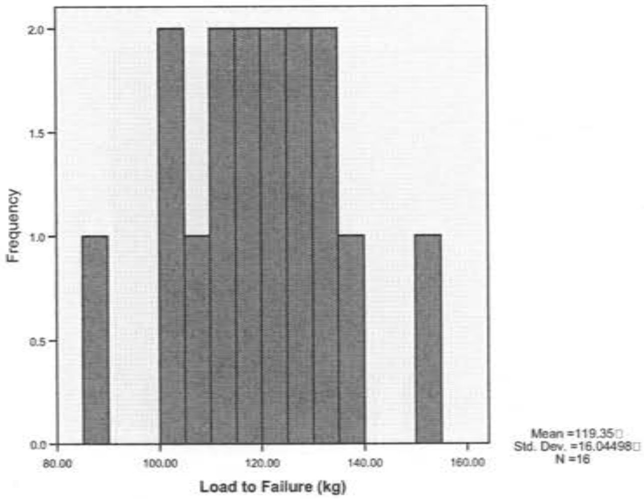
Table 1. Force at Failure of Veneer after a year of Fatigue

Crown Name	*Force ± SD*
NuSmile	119.35 Kg ± 16.04 Kg (1,170.42 N ± 157.29 N)
Cheng	66.60 Kg ± 28.00 (653.12 N ± 274.59 N)
Kinder	81.15 Kg ± 21.91 (795.81 N ± 214.86 N)

Appendix A. NuSmile Crowns Statistics

Descriptives

	Type of Crown			Statistic	Std. Error
Load to Failure (kg)	NuSmile Failure (kg)	Mean		119.3500	4.01124
		95% Confidence Interval for Mean	Lower Bound	110.8002	
			Upper Bound	127.8998	
		5% Trimmed Mean		119.3944	
		Median		119.1500	
		Variance		257.441	
		Std. Deviation		16.04498	
		Minimum		85.60	
		Maximum		152.30	
		Range		66.70	
		Interquartile Range		22.48	
		Skewness		-.068	.564
		Kurtosis		.564	1.091



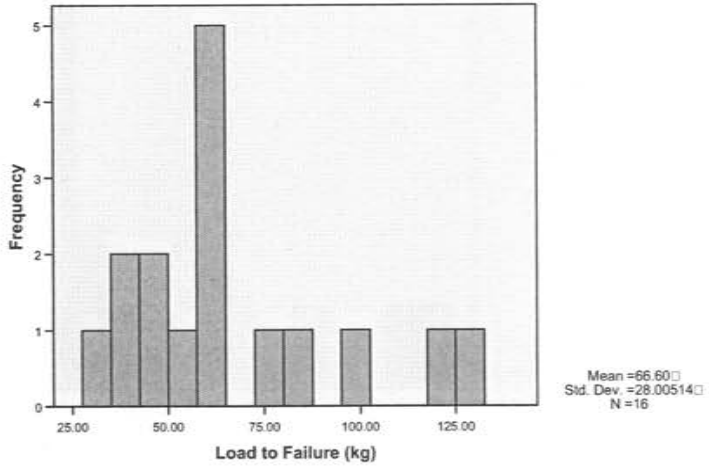
Raw Data

Samples	Load at failure	Piston
1	127.2 Kg	B
2	127.4 Kg	C
3	152.3 Kg	A
4	124.9 Kg	C
5	115.2 Kg	A
6	113.4 Kg	B
7	117.7 Kg	C
8	137.9 Kg	A
9	103.8 Kg	B
10	85.6 Kg	C
11	112.8 Kg	A
12	101.6 Kg	C
13	120.6 Kg	A
14	131.1 Kg	B
15	132.1 Kg	C
16	106.0 Kg	B

Appendix B. Cheng Crowns Statistics

Descriptives

Type of Crown				Statistic	Std. Error
Load to Failure (kg)	Cheng Failure (kg)	Mean		66.6000	7.00129
		95% Confidence Interval for Mean	Lower Bound	51.6771	
			Upper Bound	81.5229	
		5% Trimmed Mean		65.0167	
		Median		60.6500	
		Variance		784.288	
		Std. Deviation		28.00514	
		Minimum		31.70	
		Maximum		130.00	
		Range		98.30	
		Interquartile Range		34.85	
		Skewness		1.105	.564
		Kurtosis		.639	1.091



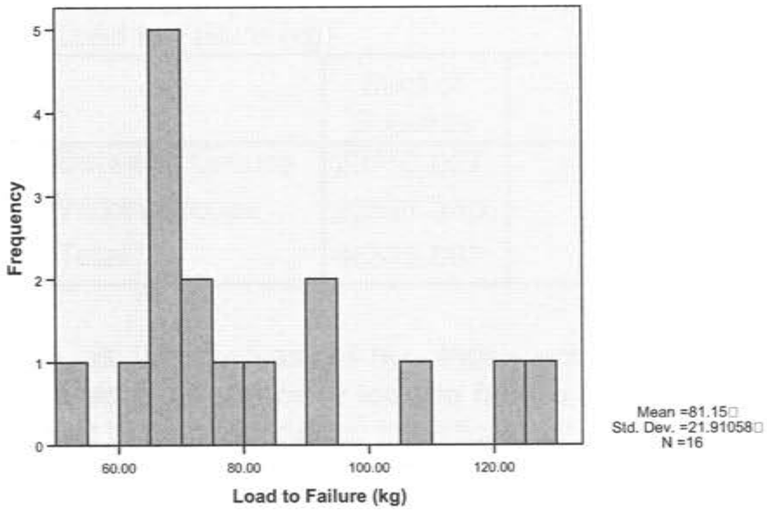
Raw Data

Samples	Load at Failure	Piston
1	96.6 Kg	C
2	130.0 Kg	A
3	79.6 Kg	B
4	117.8 Kg	A
5	49.4 Kg	B
6	44.0 Kg	C
7	80.4 Kg	A
8	50.7 Kg	B
9	42.0 Kg	C
10	63.2 Kg	A
11	38.0 Kg	B
12	61.4 Kg	A
13	59.0 Kg	B
14	59.9 Kg	C
15	61.9 kg	A
16	31.7 Kg	C

Appendix C. Kinder Crowns Statistics

Descriptives

	Type of Crown			Statistic	Std. Error
Load to Failure (kg)					
	Kinder Failure	Mean		81.1500	5.47764
		95% Confidence Interval for Mean	Lower Bound	69.4747	
			Upper Bound	92.8253	
		5% Trimmed Mean		80.0500	
		Median		72.6500	
		Variance		480.073	
		Std. Deviation		21.91058	
		Minimum		53.60	
		Maximum		128.50	
		Range		74.90	
		Interquartile Range		27.50	
		Skewness		1.121	.564
		Kurtosis		.394	1.091



Raw Data

Samples	Load at Failure	Piston
1	66.7 Kg	A
2*	128.5 Kg	B
3	83.7 Kg	C
4*	105.4 Kg	B
5	94.7 Kg	C
6	73.6 Kg	A
7*	66.6 Kg	B
8	65.0 Kg	C
9	66.1 Kg	A
10	66.1 Kg	B
11*	71.7 Kg	C
12	90.3 Kg	B
13	123.3 Kg	C
14*	78.5 Kg	A
15	64.6 Kg	B
16	53.6.Kg	A

*Crown broke; was replaced

Appendix D. Statistical Analysis

ANOVA: Analysis of Variance-

used to detect statistical significant differences between groups.

Null Hypothesis: There is no difference in the load to failure after a year of fatigue between the groups of crowns (NuSmile, Cheng and Kinder).

Alternate hypothesis: There is a difference in the load to failure after a year of fatigue between the groups of crowns (NuSmile, Cheng and Kinder).

α = 0.05 (level of significance)

ANOVA

Load to Failure (kg)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	23752.027	2	11876.013	23.412	.000
Within Groups	22827.040	45	507.268		
Total	46579.067	47			

The ANOVA results indicates null hypothesis would be **rejected** due to a significant F-value; thus there exists a **difference in load to failure** after a year of fatigue for the 3 groups of crowns. This then allows a post-hoc test to be performed to investigate which groups are different from one another.

Appendix E. Scheffe's Post-Hoc Test

Multiple Comparisons

Dependent Variable: Load to Failure (kg)
Scheffe

(I) Type of Crown	(J) Type of Crown	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
NuSmile Failure (kg)	Cheng Failure (kg)	52.75000*	7.96294	.000	32.5916	72.9084
	Kinder Failure	38.20000*	7.96294	.000	18.0416	58.3584
Cheng Failure (kg)	NuSmile Failure (kg)	-52.75000*	7.96294	.000	-72.9084	-32.5916
	Kinder Failure	-14.55000	7.96294	.200	-34.7084	5.6084
Kinder Failure	NuSmile Failure (kg)	-38.20000*	7.96294	.000	-58.3584	-18.0416
	Cheng Failure (kg)	14.55000	7.96294	.200	-5.6084	34.7084

*. The mean difference is significant at the .05 level.

The Scheffe's Post-Hoc test indicate the following:

- NuSmile crowns are significantly different from Cheng crowns. (p<.000).
- NuSmile crowns are significantly different from Kinder crowns. (p<.000).
- Cheng crowns are not significantly different from Kinder crowns. (p<.200).