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The compressive strength of nonprecious versus precious ceramometal restorations with various frame designs

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The two main concerns regarding nonprecious alloys used in ceramometal restorations are the long-term effects on the health of the oral tissues and the ability of the restoration to withstand the stresses incurred in the oral cavity. The present study will address the latter problem.

According to Sced and McLean,[1] catastrophic failure at the bond site between the ceramic veneer and the nonprecious alloy framework can occur at any time after fabrication of the restoration. They stated that breakage could occur because of the high degree of residual stress within the ceramometal crown. A study by Delong et al.[2] demonstrated that although the bond strengths of some nonprecious alloys were not as good as gold-palladium based alloys, the bond of the nonprecious alloys appeared to be within clinically acceptable limits.

In 1971, the British Ceramic Research Association established two basic criteria for evaluation of ceramometal restorations: First, test samples should be generally similar in scale to actual clinical crowns, and second, the test samples should be fabricated by methods consistent with dental practice. At a 1981 conference of the American Dental Association (ADA) Council on Dental Materials, Instruments, and Equipment, representatives from the dental manufacturing industry, the National Association of Dental Laboratories, and the National Bureau of Standards, noted the continued lack of stan-

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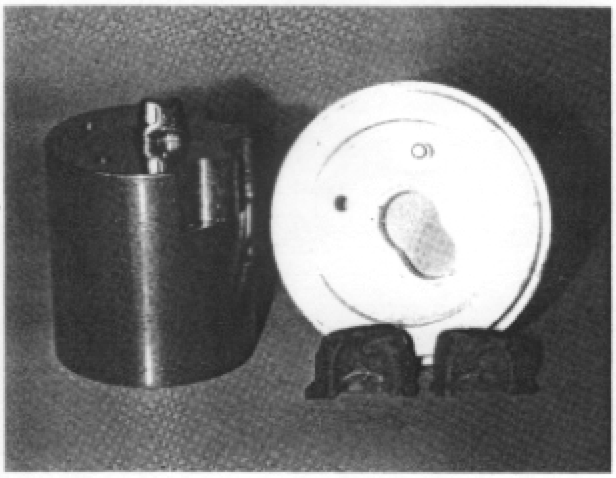

Fig. 1. Disassembled view of master die, mold relater, and design No. 2 coping mold.

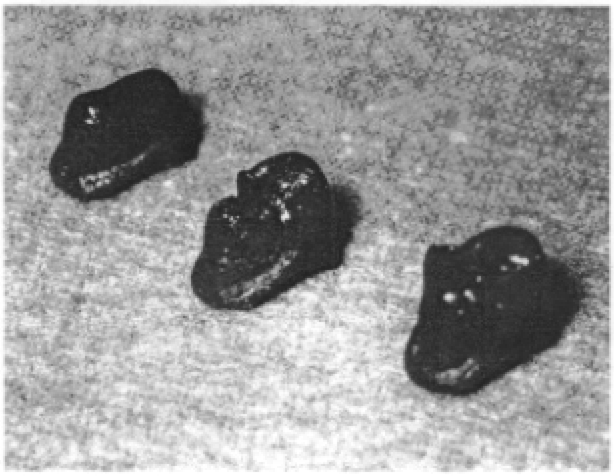

Fig. 2. Wax pattern designs No. 1, No. 2, and No. 3 from right to left fabricated in mold relater.

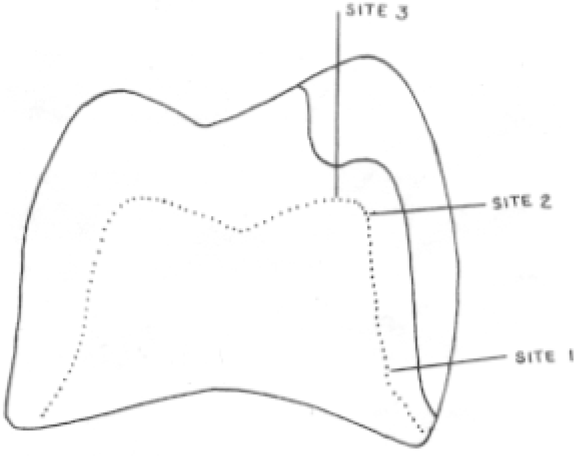

Fig. 3. Graphic depiction of design No. 1 with porcelain coverage.

dardized laboratory compatibility tests that could accurately predict clinical behavior.[3]

Previous studies[4-8] have been conducted on the evaluation of the strength of the ceramometal system, but only Nally et al.,[9] Kuhlman,[10] and Warpeha and Goodkind[11] used clinical designs.

The purpose of this study was to test ceramometal crowns, made from three different dental manufacturers' ceramometals, that simulated actual clinical crowns. Three commonly used ceramometal framework designs were evaluated for fracture resistance.

MATERIAL AND METHODS

In this study three ceramometal alloys, one precious metal (Olympia, J. F. Jelenko & Co., Armonk, N.Y.), and two nonprecious metals (Rexillium III, Jeneric Gold Co., Wallingford, Conn., and Talladium, Talladium Inc., Los Angeles, Calif.) were cast into three framework designs. Porcelain was applied to the frameworks in a manner that produced statistically comparable ceramometal test crowns for evaluation. Ceramco porcelain (Ceramco, Inc., Long Island City, N.Y.) was baked on the three metals evaluated in this study.

The following technique was used to fabricate uniform ceramo-metal test crowns. Standardized wax framework copings were made on a stainless steel master die with the use of a mold relater and plastic framework coping molds (Figs. 1 and 2). Frameworks were designed to receive porcelain on the facial cusp (design No. 1), coverage to central sulcus (design No. 2), and full porcelain coverage (design No. 3) (Figs. 3 through 5). All metals were cast and porcelain fired according to the manufacturers' instructions.

Porcelain molds were designed to ensure that test crowns would have uniform porcelain thickness (Fig. 6). Reproducible porcelain application was possible by using this technique on the first firing. A natural glaze was completed during the second firing. A total of 135 porcelain-fused-to-metal test crowns were made (Fig. 7). Forty-five test crowns of each metal were prepared. Fifteen of the samples incorporated design No. 1, 15 had design No. 2, and 15 had design No. 3. The 15 test crowns of one metal and one design are referred to herein as a group. All samples were measured at sites No. 1, No. 2, and No. 3 shown in Figs. 3 through 5 at each of the following three stages: metal only; metal and opaque; and metal, opaque, and porcelain. These measurements were recorded on each sample and the means, standard deviations, and coefficients of variation were determined. Sites No. 4 through No. 7 are found only on design No. 3 samples.

The test crowns were inspected for defects after the first application and firing of body porcelain. The metal,

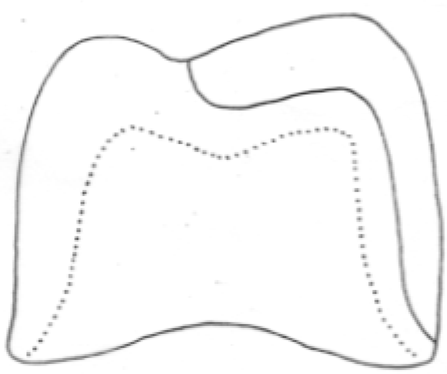

Fig. 4. Graphic depiction of design No. 2 with porcelain coverage.

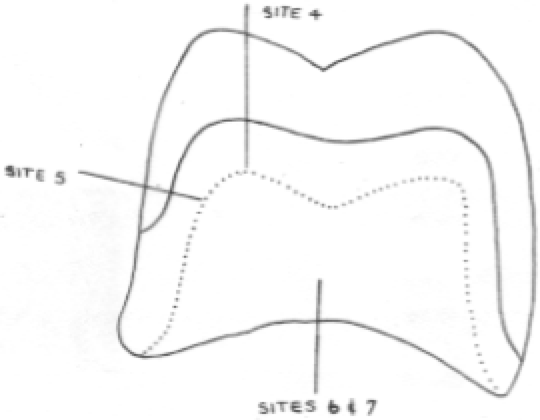

Fig. 5. Graphic depiction of design No. 3 with porcelain coverage.

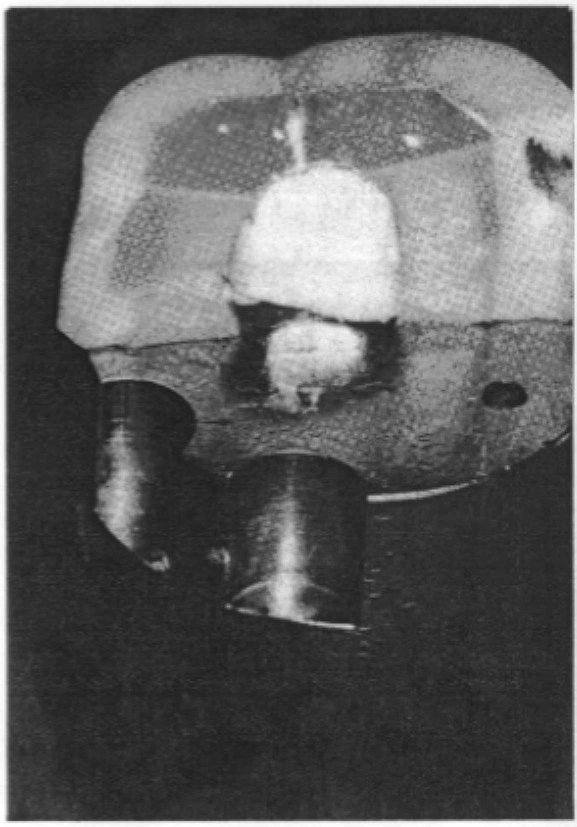

Fig. 6. Assembled master die, design No. 3 coping, and standardized porcelain mold.

design, and location of these defects were recorded. These data were totaled and percentages calculated.

The effective strengths of the test crowns were determined by cementing the test crowns to the master die. Each test crown was subjected to a load on an Instron testing machine (Instron Corp., Canton, Mass.) until catastrophic porcelain failure occurred (Fig. 8). Compression loading was applied at a crosshead rate of 0.05 inches/minute on the buccal cusp tip. Catastrophic failure of the test crowns was observed by an abrupt load drop on the Instron recording that represented the ultimate compression strength of the sample.

The data were assigned a group number from 1 to 9. Olympia designs No. 1, No. 2, and No. 3 were assigned group numbers 1, 2, and 3 respectively. Rexillium III designs No. 1, No. 2, and No. 3 were assigned group numbers 4, 5, and 6. Talladium designs No. 1, No. 2, and No. 3 were assigned group numbers 7, 8, and 9. A two-way analysis of variance of force by metal and design was carried out. Individual comparisons between means were performed by using the Student-Newman-Keuls (SNK) procedure ($p = .05$).

Visual data on the ceramometal fracture sites were collected relative to the types of fractures. O'Brien's[12] classification of metal-porcelain fractures was used to describe the fractured surfaces. The categories are: type 1, metal-porcelain separation; type II, metal oxide-porcelain separation; type III, cohesive failure within porcelain; type IV, metal-metal oxide; type V, metal oxide-metal oxide; and type VI, cohesive within metal.

RESULTS

The means and standard deviation for the seven sites are shown in Table I. The coefficients of variation of site numbers 1 through 7 of the completed test crowns ranged from 3.2% to 9.9%.

Defects in the form of tears in the porcelain or separation of the porcelain from the metal were observed in some of the test crowns. The porcelain on Olympia design No. 3 lifted or pulled up or back from the metal gingival margin without creating a vertical tear or fracture in the porcelain. The Talladium and Rexillium III alloys of design No. 3 did not lift from the gingival metal margin but cracked or formed vertical defects or

Fig. 7. Glazed samples (135) of designs No. 1, No. 2, and No. 3.

Table I. Mean of measurements in mm

Site No.	Number of samples	Metal	Metal/opaque	Metal/opaque/porcelain
1	135	0.567 ± 0.062	0.736 ± 0.088	1.362 ± 0.070
2	135	0.579 ± 0.059	0.759 ± 0.082	1.398 ± 0.046
3	135	0.840 ± 0.076	0.967 ± 0.097	2.804 ± 0.172
4	45	0.588 ± 0.133	0.760 ± 0.151	2.342 ± 0.232
5	45	0.364 ± 0.052	0.469 ± 0.064	1.387 ± 0.089
6	45	0.216 ± 0.064	0.346 ± 0.078	1.422 ± 0.067
7	45	0.241 ± 0.057	0.407 ± 0.082	1.456 ± 0.059

tears in the porcelain. Of the 135 crowns fabricated, 61 had no defects, 46 needed repair, and 28 had observable defects that did not require repair. Of the 46 repaired crowns, 45% were Talladium, 42% were Rexillium III, and 13% were Olympia.

Table II describes the means and standard deviations of force (lbs/20) by metal and design. Table III shows the analysis of variance of Table II. The *F* values in Table III indicate a highly significant difference among the three metals with a lesser effect by the design. The SNK procedure in Table IV divided the designs into two subsets. These subsets overlap allowing Talladium design No. 2 and Olympia design No. 1 to be located in both groups. Talladium design No. 1 exhibited the highest fracture resistance and Olympia design No 3, the lowest.

The fracture observed most often in the test crowns after catastrophic failure was caused by cohesive failure within the porcelain (type III). The second most common fracture appeared to be a type II fracture. Macroscopically, it appeared that the metal oxide layer seen before the application of opaque was never exposed. The fractures approximately followed the lines of stress indicated in Fig. 9.

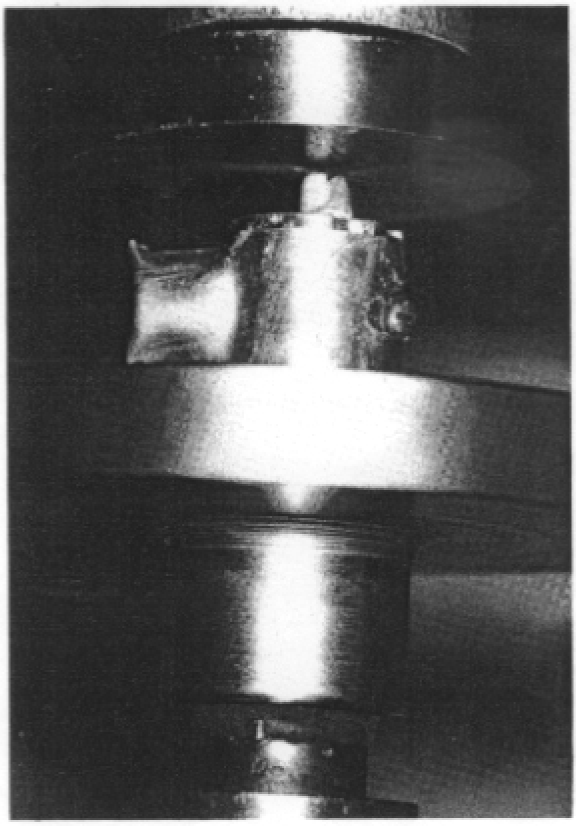

Fig. 8. Assembled master die, design No. 3 sample, and Instron machine with transducer attached.

Table II. Means of force (lbs/20) by metal and design

Metal	Design No. 1	Design No. 2	Design No. 3
Olympia	41.13 ± 13.61	37.00 ± 10.86	32.33 ± 8.33
Rexillium III	38.33 ± 6.75	36.40 ± 9.73	36.13 ± 7.08
Talladium	49.53 ± 11.81	40.40 ± 6.96	48.27 ± 10.26

DISCUSSION

The procedures done in this study have been used to produce statistically uniform ceramometal test crowns. Although different metals and multiple framework designs were used, the fabrication of the samples was within a coefficient of variance of 10%, which is considered a statistically acceptable result. The test samples were made to closely approximate clinical crown dimensions as advocated by the British Ceramic Research Association to provide information more meaningful to the dental practitioner.

Forty-six crowns had porcelain defects after the first bake and were repaired during the second bake. Of the repaired crowns, 45% were Talladium, 42% were Rex-

Table III. Analysis of variance of force (lbs/20) by metal and design

Source of variance	Sum of squares	Deviations of force	Mean^2	*F*	*p* Value
Main effects	3177.54	4	794.38	8.34	.001
Metal	2527.34	2	1263.67	13.26	.001
Design	650.19	2	325.09	3.41	.036
Two-way interaction	709.09	4	177.27	1.86	.121
Explained	3886.63	8	485.83	5.101	.001
Residual	12,000.00	126	95.23		
Total	15886.63	134	118.56		

Table IV. Force (lbs/20) to metal and design: Two subsets produced by the Student-Newman-Keuls procedure

Subset 1	Pounds of force to fracture	Subset 2
Olympia design No. 3	32.30	
Rexillium III design No. 3	36.10	
Rexillium III design No. 2	36.40	
Olympia design No. 2	37.00	
Rexillium III design No. 1	38.30	
Talladium design No. 2	40.40	Talladium design No. 2
Olympia design No. 1	41.10	Olympia design No. 1
	48.21	Talladium design No. 3
	49.50	Talladium design No. 1

illium III, and 13% were Olympia. A possible explanation for these defects resides in the thermal coefficient of expansion for the materials involved, namely, for Olympia, 0.0000146 mm/mm° C at 580° C, for Rexillium III, 0.0000142 mm/mm/° C at 700° C; for Talladium, 0.0000139 mm/mm° C at 500° C; and for Ceramco porcelain, 0.0000144 mm/mm/° C. Talladium has the lowest thermal coefficient of expansion and, therefore, the least reduction in size of cooling.* Rexillium III is second,† Ceramco porcelain is third,‡ and Olympia has the highest thermal coefficient of expansion.§ Porcelain in the molten stage contracts faster than Talladium or Rexillium III ceramometals, which places the porcelain veneer under tension and the bond site under compression. When the strength of the solidifying porcelain was exceeded, the porcelain fractured. These fractures appeared as vertical cracks that were identified with porcelain solidification. Fracturing allowed stress relief in the porcelain.[8]

Olympia ceramometal, on the other hand, contracted faster than the porcelain. The contraction placed the surface of the porcelain under compression and the bond site under tension, causing the porcelain to lift away from the metal at the margin. This was observed clinically and caused inadequate proximity of the porcelain to the metal. This explanation is qualitative in nature and is an oversimplification of the thermal behavior of the multilayered ceramometal system. Smyth[8] concluded that the mechanical condition of the surface (i.e., cracks, voids, and flaws) will influence the strength of the porcelain. It appeared in this study that opening and repairing a visible defect would lead to a stronger crown; therefore, the study concurs with Smyth's observations.

Quantitatively, the stress between porcelain and metal can be approximated by using the following formula:

$\Delta\delta$ = Stress in PSI
E = Tensile modulus of elasticity
α = Thermal coefficient of expansion

$$\Delta\delta = E(\alpha\ \text{metal} - \alpha\ \text{porcelain})(\text{C}^\circ\ \text{oven} - \text{C}^\circ\ \text{Room})$$

The tensile moduli for Olympia, Rexillium III, and Talladium ceramometals are 18,500,000 psi; 28,000,000 psi; and 26,000,000 psi, respectively. The oven temperature at glaze was 980° C and room temperature was approximately 20° C. The stress values at the bond sites were calculated and are as follows: Porcelain versus Olympia metal equals +3630 psi; porcelain versus Talladium metal equals −12,740 psi; and porcelain

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*Harms EJ: Personal communication, Talladium, Inc., Los Angeles, Calif., April 11, 1983.

†Develin R: Personal communication, Rx Jeneric Gold Co., Division of Jeneric Industries, Inc., Wallingford, Conn., November 30, 1982.

‡Panzera C: Personal communication, Johnson & Johnson Dental Products Co, East Windsor, N.J., March 15, 1985.

§Cascone P: Personal communication., J. F. Jelenko & Co., Division of Pennwalt, Armonk, N.Y., November 30, 1982.

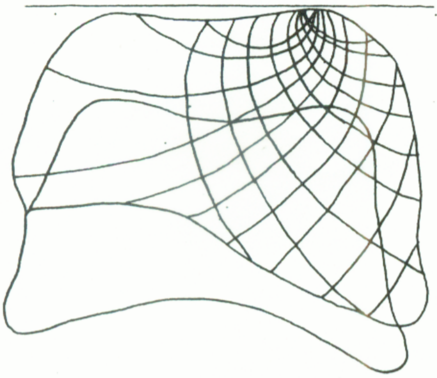

Fig. 9. Postulated shear-stress trajectories design No. 3.

versus Rexillium III metal equals −5490 psi. If the resultant number is positive, the ceramometal bond site is under tension and the porcelain is under compression. When the resultant number is negative, the bond site is under compression, and the porcelain is under tension. Porcelain versus Rexillium III or Talladium bond sites were under compression and the porcelain versus Olympia bond site was under tension. These calculations offer further explanation for the vertical fracture in both of the nonprecious alloy systems tested. Vertical tears appeared to release residual stress and made the repaired test crowns stronger than the test crowns that did not need repair.

The coefficient of thermal expansion of porcelain varies with the location of its manufacture.*[12] European porcelains commonly have lower coefficients of thermal expansion, American porcelains have medium coefficients of thermal expansion, and Japanese porcelains have varied coefficients of thermal expansion from low to high.* The coefficient of thermal expansion varies with temperature[13] and degree of vitrification.* Clinically, attention must be given to the coefficient of thermal expansion of the metal and the porcelain. The Talladium Corporation specifically fabricates two different formulations of metal to match the various porcelain products being sold to commercial laboratories. This metal-to-porcelain matching is necessary to ensure a more uniform ceramometal bond.

According to Craig et al.,[4] Farah and Craig,[5] and Nally et al.,[9] porcelain fails primarily in shear when loaded in compression. Photoelastic studies have shown that the area of a material under a rigid punch shows isochromatic shearing-stress trajectories radiating from the edges of the punch. Fig. 9 represents a composite of fracture lines observed in the porcelain samples (Figs. 10 through 12). This illustration compares favorably with the stress trajectories observed by Warpeha and Goodkind,[11] Nally et al.,[9] and Farah and Craig.[5] In their studies, they stated that shearing stress trajectories intersect the lines at a 45-degree angle to form a system of curves. These lines coincide with the direction that demonstrates shearing-type stresses. Note that in Fig. 9, the stress concentration increases toward the edges of the loading area. Fractures in porcelain would start at these edges and proceed along the lines of the shearing-stress trajectories. The areas to the edge of the load surface are in tension or shear and the area under the load cell area is in compression. On the other hand, some fractures may have initiated at the bond site.

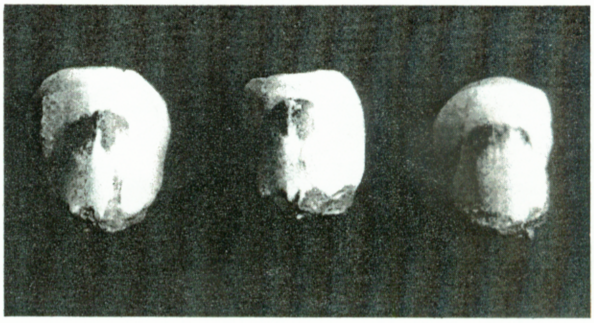

Fig. 10. Fractured Talladium samples, from left to right, designs No. 1, No. 2, and No. 3.

Table IV gives the results of the SNK procedure as applied to the force data. The SNK procedure, when using both the mean of the force by groups and the variance within the groups, produced two overlapping subsets of groups. The low subset (subset 1) ranged from Olympia design No. 3 at 646 pounds of force to Olympia design No. 1 at 822 pounds of force. The high subset (subset 2) ranged from Talladium design No. 2 at 808 pounds of force to Talladium design No. 1 at 990 pounds of force. The samples in Kuhlmann's[10] and Warpeha and Goodkind's[11] studies had high force means of 220 pounds and 401 pounds. Kuhlmann[10] used Aderer Ceramo gold (Sybron/Kerr, Romulus, Mich.) and Warpeha and Goodkind[11] used Ceramco "O" manufactured by Jelenko. Their high means are still two to five times lower than the 990-pound high mean for Talladium design No. 1 observed in this study. This discrepancy can be accounted for in part by the physical properties of the different metals used in each study and in part by the method of fixing the crown to the die.

The pounds of force required to cause simulated clinical failure of the crown on the Instron recording are used only as a relative basis of comparison. Delong et al.[2] tested Rexillium III (15,000 psi bond strength) and Olympia (31,000 psi bond strength) by using a shear push-through test. The results in Table III indicated that Olympia and Rexillium III materials in all designs were placed in subset 1 and, therefore, were considered

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*Harms EJ: Personal communication, Talladium, Inc., Los Angeles, Calif., April 11, 1983.

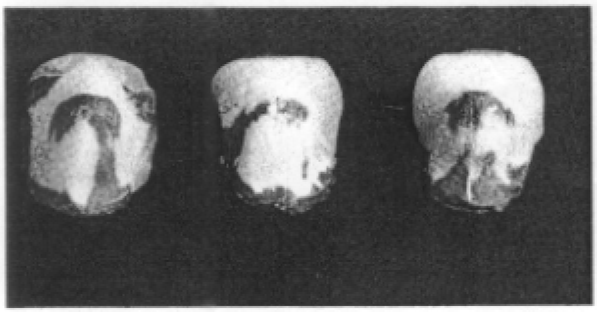

Fig. 11. Fractured Rexillium III samples, from left to right, designs No. 1, No. 2, and No. 3.

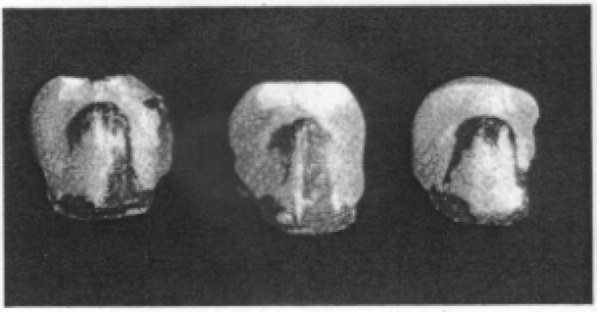

Fig. 12. Fractured Olympia samples, from left to right, designs No. 1, No. 2, and No. 3.

statistically the same in terms of pounds of force needed to cause failure. The only difference between these two samples was the metal used. The chemical bond strength of nonprecious alloys appeared to be less than that of precious alloys in the Delong et al.[2] study. The effect of this difference in apparent bond strength cannot be directly related to the present study because, the measurement technique was different and because it is not clear how much the present results depend on the true bond strength. It can only be assumed that the present comparable strength results with Olympia and Rexillium alloys can be explained by the superior physical properties of Rexillium III alloy. Riley[14] stated that the higher the ultimate tensile strength and the higher the modulus of elasticity, the better the substructure for porcelain. It appears that the physical properties of the nonprecious alloys have compensated for any greater bond strength that gold-palladium based alloys might have.

Talladium alloy, a metal not tested by Delong et al.[2] for bond strength, had a higher mean force in all designs than Olympia and Rexillium III alloys. Talladium alloy has approximately the same physical properties of Rexillium III alloy.* Therefore, the greater crown strength of Talladium may be due to either a higher bond strength or the state of residual stress at the bond site.[15, 16] That is, the Talladium alloy has the greatest compressive stress of the three ceramometal systems, more than twice that of Rexillium. If the delay in bond site fracture is aided by the residual compressive stress, this could partly explain the observed differences. The superiority of Talladium over Rexillium III alloy may also be due to the trace element composition and the infiltration of ferric aluminum oxide during the mechanical preparation of the metal before porcelain application.*

These tests demonstrated that design No. 1 required the greatest force to cause failure. Table IV indicated that Olympia, Rexillium III, and Talladium in design No. 1 were the hardest to break. The superiority of partial porcelain coverage versus full coverage has been discussed by Hobo et al.[6] and others.[5, 7-9] The arguments for and against each design usually are based on clinical assumptions. Kuhlmann's[10] study strongly indicated that design No. 1 (partial coverage) is more resistant to fracture under load-control conditions than are the full coverage crowns (Table II). This may be due to the greater mass of metal in design No. 1, which provided better resistance to the elastic deformation of the crown. Statistically, Talladium alloy had higher force values primarily because of its metal structure rather than the various framework designs, as indicated in Table III. Clinical application of design No. 1 (i.e., partial coverage) over a 12-year period confirms this,* but should not deter any clinician from using designs No. 2 or No. 3 in a clinical situation. Bond strength may not be the only criterion used for selecting a metal for a clinical framework.

SUMMARY

This study was designed as a comparative analysis of the compressive strengths of precious versus nonprecious metals with various framework designs used in clinical restorations. One hundred thirty-five statistically uniform ceramometal restorations were fabricated. The restorations were cemented to the die and then subjected to stroke-control compression forces in an Instron loading machine. Simulated clinical failure was recorded by the Instron load cell recorder in pounds of load.

CONCLUSIONS

1. Covering of facial cusps with porcelain as in design No. 1 produced the greatest fracture resistance.

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*Harms EJ: Personal communication, Talladium, Inc., Los Angeles, Calif., June 30, 1983.

*Goodkind RJ: Personal communications, Professor and Director of Graduate Prosthodontics, University of Minneapolis, Minn., 1984.

2. Talladium ceramometal test crowns were stronger than Olympia and Rexillium III crowns in designs No. 1, No. 2, and No. 3.

3. It appeared that the metal's physical and mechanical properties and the residual stress at the bond site had a greater effect on the ultimate fracture strength of the crown than did the design of the metal framework.

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