# The effectiveness of auxiliary features on a tooth preparation with inadequate resistance form

**Periklis Proussaefs, DDS, MS,[a] Wayne Campagni, DDS,[b] Guillermo Bernal, DDS, MSD,[c] Charles Goodacre, DDS, MSD,[d] and Jay Kim, PhD[e]**
School of Dentistry, Loma Linda University, Loma Linda, Calif

**Statement of problem.** No study has evaluated the efficacy of auxiliary tooth preparation elements for crowns with originally reduced resistance form.

**Purpose.** This study evaluated the effects of different auxiliary preparation features on the resistance form of crowns with reduced axial wall and total occlusal convergence.

**Material and methods.** An Ivorine tooth was prepared on a milling machine with 20-degree total occlusal convergence (TOC), 2.5 mm of occlusocervical dimension, and a shoulder finish line. This design lacked geometric resistance form. The crown preparation was subsequently modified to include mesiodistal grooves, mesiodistal boxes, buccolingual grooves, occlusal inclined planes, an occlusal isthmus, and reduced TOC in the axial wall from 20 to 8 degrees TOC in the cervical 1.5 mm of the axial wall. The grooves and boxes were placed into the tooth with the same 20-degree TOC as the initial axial walls. Ten standardized metal dies were used for each preparation design. Standardized complete metal crowns were fabricated for all specimens. The metal crowns were cemented on metal dies with resin-modified glass ionomer cement. A strain gauge was placed at the mid-lingual cervical area of each crown preparation margin. The resistance of each specimen was evaluated when force was applied at a 45-degree angulation to the long axis of the die in a lingual to buccal direction. The peak loads during crown dislodgment, as well as the tensile stress at the mid-lingual cervical area, were measured using a universal testing machine (Kgs) for each specimen. The control group consisted of 10 dies, with the original crown preparation having no geometric resistance form and no auxiliary preparation features. Strain gauges provided the force (Kgs) that resulted in electric currency disrupt at the crown/die interface, thus providing data regarding the force required for slight crown micromovement (2 $\mu$m). Data between control and experimental groups were compared using the Mann-Whitney *U* test ($\alpha$=.05).

**Results.** Proximal grooves, proximal boxes, buccolingual grooves, occlusal inclined planes, and occlusal isthmuses were not effective at increasing a crown's resistance to dislodgement when the tooth preparation lacked resistance. The only crown modification that offered enhanced resistance form when compared with the control group was the reduced TOC in the cervical half of the axial wall.

**Conclusion.** Within the limitations of this in vitro study the crown preparation modification that significantly enhanced the resistance form of a compromised tooth preparation was reducing the TOC at the cervical aspect of the axial wall. Placing auxiliary retentive features such as grooves and boxes into a compromised tooth preparation (2.5 mm occlusocervical dimension and 20-degree TOC) was not effective when these retentive features possessed the same 20-degree TOC as the prepared axial walls. (J Prosthet Dent 2004;91:33-41.)

## CLINICAL IMPLICATIONS

*In this in vitro study, for a compromised situation in which a crown preparation had reduced resistance form (reduced axial wall height and/or reduced total occlusal convergence), the auxiliary preparation element that most effectively enhanced resistance form of the crown was reducing the cervical total occlusal convergence from 20 to 8 degrees.*

Resistance form is defined as "the features of a tooth preparation that enhance the stability of a restoration and resist dislodgment along an axis other than the path of placement."[1] The tooth preparation designs that offer resistance form to a tooth have been studied extensively; however, the initial reports in the literature were focused on the retention form of tooth preparations.[2-4] The significance and clinical relevance of resistance form were subsequently investigated.[5-12] Several parameters can affect the resistance of a tooth to forces applied on an axis

Sponsored by American Academy of Fixed Prosthodontics /Tylman Research Grant 2000 and the Loma Linda University Graduate Thesis Committee. Received 1st Place Tylman Award in 2002.

[a]Assistant Professor, Center for Prosthodontics and Implant Dentistry; and Private practice, Santa Clarita, Calif.
[b]Professor and Director, Advanced Education in Prosthodontics.
[c]Associate Professor, Advanced Education in Prosthodontics.
[d]Professor and Dean, Loma Linda University School of Dentistry.
[e]Professor in Biostatistics, Education Services.

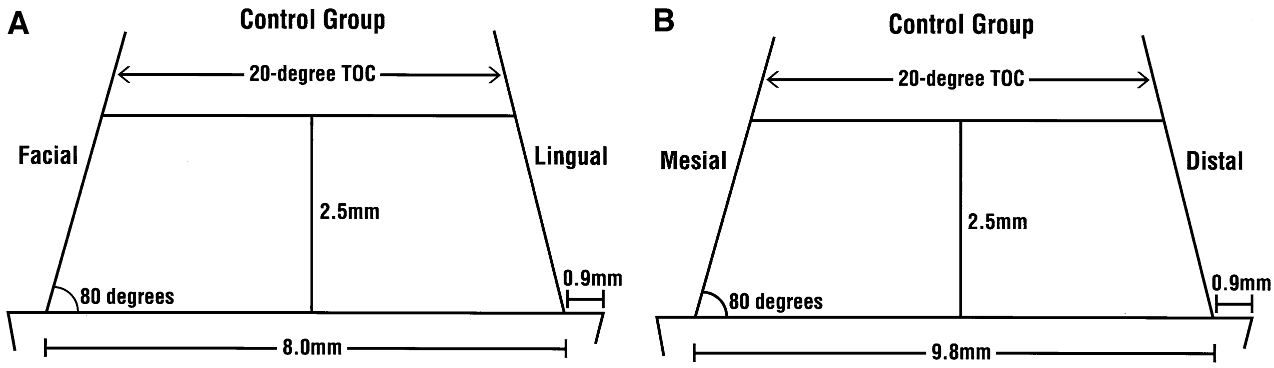


**Fig. 1.** Control Group: **A**, Mesiodistal and **B**, faciolingual view.

other than the path of placement.[5] The parameters can be divided into those that are related to the tooth preparation design and those related to the crown fabrication and modification.

Reisbick and Shillingburg[5] were the first to investigate the features of a crown preparation that increased resistance form. They reported that the placement of interproximal grooves and boxes increased the resistance form of the tooth preparation. In addition, they reported that the placement of boxes was more effective than prepared grooves. Woolsey and Matich[6] confirmed Reisbick's theory, emphasizing the importance of the location of the grooves. Grooves placed in an interproximal location can offer improved resistance over grooves placed in a buccolingual location provided that the forces are applied in a buccolingual direction. Potts et al,[7] Kishimoto et al,[8] and Owen[9] further emphasized the importance of the placement of grooves to the resistance form of a tooth preparation.

Other preparation design features in a crown preparation may affect the resistance form. The total occlusal convergence (TOC),[10,11] the occlusocervical dimension of the preparation design,[12] and the diameter of the crown preparation[12] have been reported as important factors that affect the resistance form. A linear relation has been documented for these parameters and the final resistance form. However, Parker et al[13] and Zuckerman[14] demonstrated through a mathematical analysis that the resistance form has an "on-off nature." The controversy of whether the form of resistance is linear or has an "on-off" nature still remains, as in vitro studies[5-7] have demonstrated conclusions different from mathematical analysis. The findings of such studies suggest that increasing the height and diameter of the crown preparation and decreasing the total occlusal convergence decrease the likelihood that a crown will be dislodged under function.

In vivo studies[13,15-19] have shown that TOC is not consistent and deviates from the definition of an "ideal" resistance form. Tooth location is a critical factor in achieving adequate resistance form in preparation taper.[13,18,19] The molar region frequently possesses the most inadequate total occlusal convergence.[13,18,19] It has been reported that in consistently overtapered crown preparations, auxiliary elements such as grooves are rarely used.[13]

The design of the occlusal surface of the preparation can also affect the resistance form of a crown preparation. Zuckerman[14] has shown by using a mathematical model that the placement of inclined planes on the occlusal surface of a crown preparation rather than a flat surface can increase the resistance form. The same can be achieved by the placement of an occlusal isthmus.

The resistance form of a crown preparation can be further improved by re-preparing the apical portion of the axial walls at a reduced or more "ideal" TOC.[14] This modification reduces the diameter of the boundary circle that defines the areas of the preparation that can potentially offer resistance. However, the mathematical models of Zuckerman[14] and Parker et al[13] have used the assumption that an intimate and uniform contact exists between the crown and the die. Several studies have shown that because of the space needed for the cement, and because of casting limitations, such an intimate and uniform contact does not exist.[20-24] Other authors have reported that the compressive strength of the cement between the internal surface of the crown and the tooth surface is a determining factor regarding the resistance of a crown.[25,26] The purpose of this study was to evaluate the effect of auxiliary preparation elements and occlusal surface modifications on the resistance form of a complete metal crown in the molar area.

## MATERIAL AND METHODS

A master die was fabricated by preparing an Ivorine tooth (Columbia, Long Island, NY) that was set in a plastic base.[7] The master die was prepared using a milling machine (AF 30, Type 1369; LGA, Nürnberg, Germany) with a 10-degree tapered acrylic resin bur (Cone


**Fig. 2.** A 2.5-mm axial wall height with 20-degree TOC was prepared on die, so crown preparation lacked resistance form.

**Fig. 3.** External force was applied with universal testing machine at 45-degree angle to each crown.

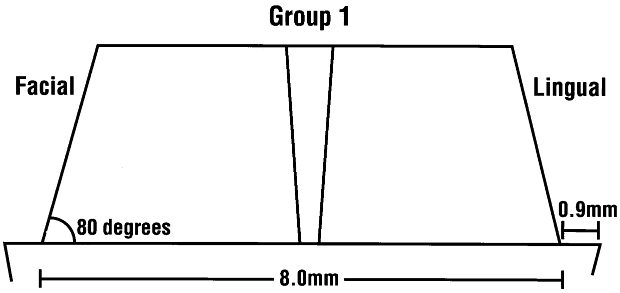


**Fig. 4.** Two interproximal grooves centered on mesial and distal surfaces of tooth.

cutter bur H356S-060; Brasseler USA, Savannah, Ga) resulting in a 20-degree TOC. This amount of TOC was selected since it represents the average angle practitioners have been demonstrated to clinically perform in the molar area.[18,19] A 0.9-mm–deep shoulder finish line was prepared. The completed tooth preparation possessed an occlusocervical dimension of 2.5 mm, an internal faciolingual dimension of 8.0 mm, and an external faciolingual dimension of 9.8 mm (Fig. 1). The occlusocervical/faciolingual ratio was .26 when the external tooth dimension was used in the ratio calculation. The ratio was .31 when the faciolingual dimension between the prepared facial and lingual walls was used to calculate the ratio. Neither ratio met the minimally acceptable value proposed for molars.[27] The occlusal surface was prepared with a flat form by using a 0-degree nontapered acrylic-resin finishing bur (Parallel cutter carbide milling bur H364E-023; Brasseler USA) and by placing the Ivorine tooth at a 90-degree angle to the long axis of the bur. A 0.5-mm–wide bevel was placed between the axial walls and the occlusal surface of the preparation at 45 degrees to the occlusal surface (Fig. 2).

The tooth preparation was judged to lack adequate resistance form according to recently proposed criteria.[27] To further evaluate the potential resistance form of this tooth preparation, the faciolingual distance between the most apical areas of the buccal and lingual axial walls at the mesiodistal center of the prepared tooth was measured with a caliper (Darby Dental Supply Inc, Pompano Beach, Fla). This measurement determined the radius of the boundary circle within which the preparation design would not offer any resistance form, according to Zuckerman.[14] The occlusal surface of the preparation was reduced so that the axial walls were included within the boundary circle. In this way, the tooth preparation had no mathematical resistance form.

One impression was made of the definitive preparation using high-viscosity vinyl polysiloxane impression material (Aquasil LV; Dentsply International Inc, York, Pa) loaded in a custom-made tray fabricated from photopolymerized acrylic resin (Triad; Dentsply International Inc). The impression of the definitive Ivorine tooth preparation was used to fabricate 10 wax patterns (Pro-Art; Ivoclar Vivadent Inc, Amherst, NY) of the

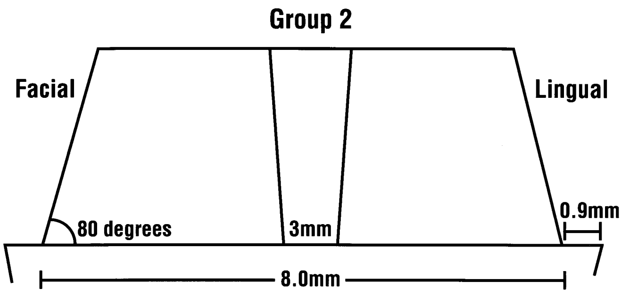


**Fig. 5.** Interproximal grooves transformed to interproximal boxes.

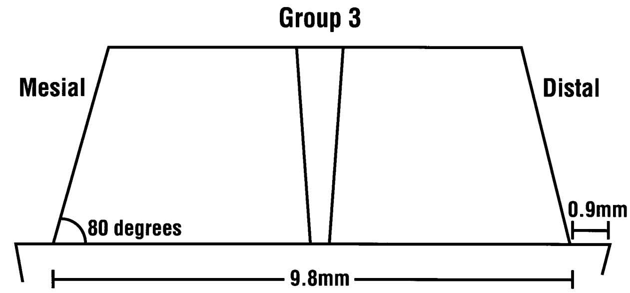


**Fig. 6.** Two grooves prepared into mid-buccal and mid-lingual surfaces.

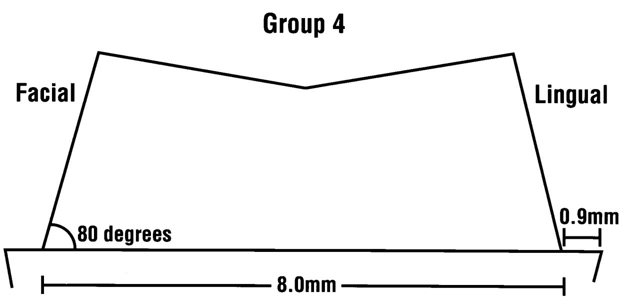


**Fig. 7.** Occlusal surface prepared with inclined planes parallel to original inclined planes of cusps.

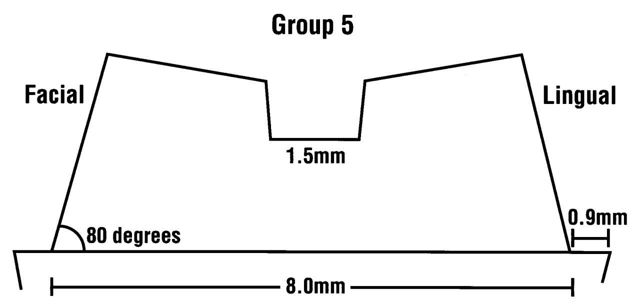


**Fig. 8.** Prepared occlusal isthmus.

tooth preparation numbered 1 to 10 to identify the die number. Two sprue formers were placed (Tri-wax; Pro-Art, Williams, Amherst, NY) at the lateral aspect of the wax patterns. Two wax patterns were attached to each crucible former and invested (Fastfire; Whip Mix, Louisville, Ky). A ratio of 20:4 of special liquid to distilled water was used.

Base metal alloy (Will-Ceram Litecast–B, composition: Ni 77.4%, Cr 12.8%, Mo 4%, Al 3.3%, Be 1.8%, Fe 1%; Pro-Art, Williams) was used to fabricate 10 metal dies. Die lubricant ("Keen Lube"; Belle de St Claire, Chatsworth, Calif) was applied to the surface of the metal die. A wax pattern of the definitive crown (Pro-Art, Williams) was then made on this die.[28] Soft wax ("Cervical wax"; Pro-Art, Williams) was used for the area around the margin of the wax patterns. A recipient site for the tip of the universal testing machine was carved at the buccal site of the pattern. A vinyl polysiloxane material (Aquasil HV; Dentsply International Inc) in a custom tray was used to make an impression of the definitive wax pattern. This impression was used as a mold to standardize the fabrication of 10 crowns using the same investment, special liquid to distilled water ratio, and metal as described for the fabrication of the metal dies. Use of a base metal alloy for the crowns offered enhanced compressive strength and resistance to deformation during testing.[29]

The fit of each crown was visually verified under a microscope (Model Z30L; Leica Inc, Buffalo, NY). Disclosing material (Occlude; Pascal, Bellevue, Wash) was used to identify areas that prevented complete seating of the restorations. The intaglio surfaces of the castings were adjusted to allow complete seating of the crowns. The crowns as well as the metal dies were subjected to airborne-particle abrasion using 50-$\mu$m $Al_2O_3$ before cementation.

The first 10 crowns were cemented onto the metal dies with a resin modified glass ionomer (Vitremer; 3M, St. Paul, Minn). A 5-kg load[20] was applied to the crown while the cement was setting. Each crown was loaded for a minimum of 2 minutes. The cement was allowed to set for 24 hours. One strain gauge (Pre-wired strain gauges; Omega Engineering Inc, Stamford, Conn) was placed at the midlingual cervical area of the preparations. The strain gauges were secured with cyanoacrylate (Super glue; Super Glue Co, Rancho Cucamonga, Calif). The purpose of the strain gauges was to identify the first signs of crown dislodgement. Strain gauges recorded discontinuity of electricity through the gauge caused by slight micromovement along the area where the strain gauge was attached (midlingual area of the crowns). According to the manufacturer, 2 $\mu$m of micromovement results in a paucity of electric supply through the strain gauge. Because strain gauges did not measure "strain" but the actual force under which slight micromovement on the

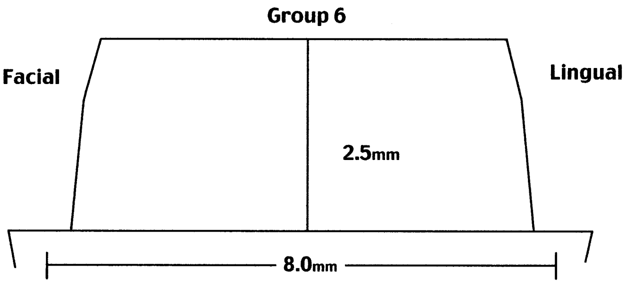


**Fig. 9.** Apical 1.5 mm of crown prepared with reduced TOC of 8 degrees.

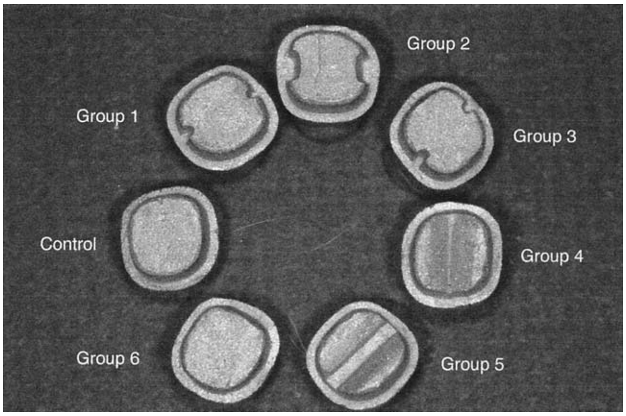


**Fig. 10.** One control and 6 experimental groups (n=10 dies and crowns).

crowns occurs and paucity of electric supply, no strain gauge calibration was performed. One active arm was used on the bridge amplifier (model 3800; Measurements Group, Raleigh, NC) for each crown specimen.

The cemented crowns were loaded with a gradually increased external force (Kgs) applied at a 45-degree angulation[7] from a lingual to buccal direction by a universal testing machine (model 1125; Instron Corp, Canton, Mass) (Fig. 3). The force was applied at the lingual inclined plane of the buccal cusp (Fig. 3). Records were made of the force required for crown dislodgement in the universal testing machine. The force in Kgs required for interruption of current on the strain gauges (2-$\mu$m micromovement) was also recorded.

The Ivorine tooth used for the initial group was modified by preparing 2 interproximal grooves centered on the mesial and distal surfaces of the Ivorine tooth.[5-9] This die served as the definitive die for this group and was tested to determine the effect of grooves on resistance. The grooves were prepared using a carbide bur (171; Darby Dental Supply Co) and the same milling machine. The grooves were extended from the occlusal surface of the preparation to the level of the finish line.[6] The faciolingual dimension of the grooves at their cervical termination was 1.0 mm. The grooves were 1.0 mm in mesiodistal depth (Fig. 4). An impression was made using the previously described materials and method as for the initial crown preparation for the control group. Ten metal dies and 10 crowns were fabricated. The crowns were again disclosed and internally adjusted for complete seating. After confirmation of complete seating under the microscope, the crowns were evaluated for resistance by finger pressure to detect whether they were displaced. The restorations were cemented with resin reinforced glass ionomer cement using the same protocol. The restorations were dislodged using the same angulation in the universal machine. The dislodging force, as well as the tensile stress at the mid-cervical area, was recorded.

The interproximal grooves were then transformed to interproximal boxes[5,8] using the same carbide bur and extending the grooves buccally and lingually. This resulted in proximal boxes with 3 mm of faciolingual dimension at the gingival floor. The boxes were 1.0 mm in mesiodistal depth (Fig. 5). By following the same protocol of die and crown fabrication and measurement of lateral dislodging force and mid-cervical stress, the effect of interproximal boxes on crown resistance was assessed.

Sculpting wax (Pro-Art, Williams) was applied to the interproximal boxes of the Ivorine tooth to block out the prepared boxes.[7] Two grooves (1 mm in mesiodistal and faciolingual dimensions) were prepared into the midbuccal and midlingual surfaces of the tooth using the same carbide bur and extending the grooves mesiodistally until they reached the desired dimensions (Fig. 6). An impression of the Ivorine tooth was made, and 10 metal dies were cast. By using the same impression index, 10 crowns were fabricated and their resistance to dislodging forces was measured. The strain gauges again provided a measurement of the tensile stress at the cervical area.

Two more crown modifications were evaluated. The occlusal surface was prepared with inclined planes parallel to the original inclined planes of the cusps.[14] Wax was placed to seal the buccal and lingual grooves previously prepared. The occlusal surface was prepared at a 30-degree angulation to follow the original cusp inclinations of the unprepared tooth. Two inclined planes were prepared: buccal and lingual (Fig. 7). The Ivorine tooth was placed on the holder of the milling machine to standardize the 30-degree angulation. A 0-degree tapered acrylic resin bur was used. After the fabrication of 10 metal dies and 10 complete metal crowns, the resistance of the crowns was recorded by following the previously described protocol. The occlusal surface was further modified by incorporating an isthmus, 1 mm in occluso-cervical depth and 1.5 mm in faciolingual dimension[21] (Fig. 8) using a 4-degree tapered acrylic resin finishing bur (Cone cutter H356S-031; Brasseler USA) in the milling machine. The effect of the isthmus on the resistance form was measured using the same protocol.

After restoring the prepared site of the Ivorine tooth with wax, the original preparation was further modified using the same 4-degree tapered acrylic resin finishing bur on the milling machine and preparing the apical portion of the crown with a reduced TOC of 8 degrees (Group 6).[14] The reduced TOC was present in the cervical 1.5 mm of the prepared axial surfaces. This additional reduction resulted in a preparation with cervical dimensions of 7.6 mm at the internal axiogingival line angles of the shoulder (Fig. 9). The resulting finish line depth was 1.1 mm. Ten metal crowns were then fabricated, and the resistance and cervical stress of the crowns were measured using the same protocol. In total, 1 control and 6 experimental groups were formed (Fig. 10), each having 10 metal dies and 10 crowns.

### Statistical analysis

Using a Mann-Whitney *U* test ($\alpha$=.05), the values obtained from the strain gauges and those obtained by the universal testing machine were compared between the different groups. Parametric tests were not used because the data were not normally distributed according to Lillifors test for normality; therefore, nonparametric tests were used.

## RESULTS

The data from the strain gauges, as well as the mechanical forces required for the mechanical dislodgement of the crowns, were recorded (Tables I and II). When evaluating the data obtained through the universal testing machine, the Mann-Whitney rank test demonstrated that the values observed by reducing the TOC of the original preparation design at the cervical area were significantly higher than all the other modifications (Table III). Interestingly, no significant difference was observed between the control group and any of the crown preparation modifications except for reducing the TOC at the cervical 1.5 mm of the axial wall.

Similar observations were made when evaluating the data obtained through the strain gauges. The only crown preparation modification that offered significantly increased values as compared to the control group was the modification in which the TOC had been decreased from 20 to 8 degrees in the cervical 1.5 mm of the axial wall (Table IV).

## DISCUSSION

This study demonstrated that in a laboratory simulation of a clinically compromised complete-coverage tooth preparation including reduced occlusocervical dimension, increased TOC, and a reduced occlusocervical-to-occlusolingual dimension ratio, the crown preparation modification that offered the greatest resistance form was the preparation of the die with 8 degrees of total occlusal convergence at the apical 1.5 mm of the axial wall. The other tooth preparation modifications were not effective.

In this study, grooves and boxes were not effective at increasing resistance form for a short tooth preparation with 20 degrees TOC. The grooves and boxes may not have been effective because they were placed into the tooth following the existing 20-degree TOC of the axial walls. Perhaps they would have been effective if they had been formed with less TOC, such as the 8 degrees of TOC present in the cervical portion of the axial walls of Group 6 that proved to be effective at increasing resistance to dislodgement.

By applying this modification of decreased TOC, the outline of the crown preparation became located beyond the margins of the boundary circle described by Zuckerman.[14] According to Zuckerman's theory,[14] the design of a crown preparation has an "on-off nature." A boundary circle defines the presence or the lack of resistance in a crown preparation.[14] If the outline of the prepared tooth is located within the circle, there is sufficient resistance; if the outline is located beyond the circle, the crown lacks geometric resistance. This study did not support Zuckerman's theory for the specific form and dimensions of the tooth preparation indications used. This lack of support may have been due to the intervening space and material located between the internal surface of the crown and the prepared tooth surfaces.

Teteruck and Mumford[20] investigated the degree of adaptation with different crown modifications. It was consistently found that along grooves and interproximal boxes there was an increased gap or loss of adaptation between the die and the crown. In preparations with grooves, the positive contact area observed between the die and the crown was located at the groove/occlusal surface region and never in the cervical region, which theoretically would offer the greatest resistance. Similarly, a lack of intimate adaptation of the casting was also consistently found at the area of the boxes. The reason for the reduced internal adaptation in those different casting shapes is not known.[21] The geometric form might have had some restrictive effect on the setting expansion of the investment. In an in vitro study, Fusayama and Ogata[22] demonstrated that if a column, a crown, or an MOD onlay were cast, a difference existed in the amount of casting shrinkage. Casting shrinkages in different mold forms vary, depending on the degree in which mold walls reduce the shrinkage of solidifying alloys. Kono and Fusayama[21] also found that irregularly shaped castings exhibit a higher degree of shrinkage compared to a rod-shaped casting. In addition, Morey[23] also found different degrees of shrinkage on different crown shapes. Morey concluded that for a given alloy, the inherent casting shrinkage is determined only by its

**Table I.** Strain gauge measurements (Kgs): first micromovement

| Resistance test | Control group | Mesiodistal grooves | Mesiodistal boxes | Buccal-lingual grooves | Occlusal inclined planes | Occlusal isthmus | Reduced TOC |
|---|---|---|---|---|---|---|---|
| 1 | 70.05 | 119.72 | 200.72 | 190.69 | 259.11 | 192.85 | 334.50 |
| 2 | 149.89 | 58.05 | 85.34 | 97.65 | 108.33 | 106.27 | 269.81 |
| 3 | 86.98 | 132.29 | 193.16 | 291.25 | 127.22 | 50.54 | 193.21 |
| 4 | 105.03 | 98.09 | 100.49 | 153.09 | 165.80 | 52.96 | 186.85 |
| 5 | 107.48 | 128.62 | 132.42 | 158.4 | 99.11 | 123.12 | 126.25 |
| 6 | 177.72 | 79.50 | 109.64 | 142.51 | 264.38 | 79.77 | 180.36 |
| 7 | 139.13 | 111.20 | 182.20 | 256.23 | 194.12 | 200.12 | 346.16 |
| 8 | 150.82 | 104.00 | 157.75 | 121.2 | 134.64 | 41.53 | 153.70 |
| 9 | 128.61 | 59.62 | 128.66 | 99.54 | 165.80 | 176.17 | 195.80 |
| 10 | 122.76 | 130.71 | 178.35 | 142.87 | 121.22 | 113.51 | 112.13 |
| Mean | 123.85 | 102.18 | 146.87 | 165.34 | 163.97 | 113.68 | 209.88 |
| SD | 32.39 | 28.09 | 41.18 | 63.98 | 59.058 | 59.46 | 81.16 |
| CV | 0.26 | 0.27 | 0.28 | 0.39 | 0.361 | 0.52 | 0.39 |

*CV,* coefficient of variation.

**Table II.** Universal testing machine data (Kgs): loosening of crown

| Resistance test | Control group | Mesiodistal grooves | Mesiodistal boxes | Buccal-lingual grooves | Occlusal inclined planes | Occlusal isthmus | Reduced TOC |
|---|---|---|---|---|---|---|---|
| 1 | 73.66 | 142.39 | 241.35 | 190.69 | 244.22 | 244.22 | 569.11 |
| 2 | 149.89 | 74.57 | 91.55 | 97.65 | 196.94 | 196.94 | 371.50 |
| 3 | 126.62 | 137.16 | 206.77 | 331.26 | 50.54 | 50.54 | 277.96 |
| 4 | 114.75 | 123.75 | 100.49 | 153.09 | 108.80 | 108.80 | 231.71 |
| 5 | 107.48 | 265.41 | 219.50 | 166.31 | 164.70 | 164.70 | 223.66 |
| 6 | 193.83 | 95.08 | 133.21 | 271.98 | 103.14 | 103.14 | 199.34 |
| 7 | 139.13 | 121.32 | 182.20 | 268.37 | 200.12 | 200.12 | 446.51 |
| 8 | 150.82 | 134.29 | 183.64 | 208.32 | 41.53 | 41.53 | 223.38 |
| 9 | 148.15 | 59.62 | 164.21 | 99.54 | 216.16 | 216.16 | 360.77 |
| 10 | 153.31 | 138.73 | 178.35 | 142.87 | 113.51 | 113.51 | 223.32 |
| Mean | 135.76 | 129.23 | 170.18 | 193.09 | 143.97 | 143.97 | 312.73 |
| SD | 32.41 | 55.77 | 49.07 | 77.40 | 0.48 | 0.48 | 121.99 |
| CV | 0.24 | 0.43 | 0.29 | 0.40 | 0.003 | 0.003 | 0.39 |

*CV,* coefficient of variation.

coefficient of thermal expansion and its solidus temperature, and the actual or observed casting shrinkage is decreased by a varying amount depending on the size and shape of the casting.

Teteruck and Mumford[20] demonstrated in more than 300 complete crown castings that the apical one third of the casting is in close proximity to the axial wall, as opposed to the cervical two thirds of the casting where an increased distance from the axial wall was consistently seen. Although the authors were unable to provide an explanation for this phenomenon, the observations were later confirmed by Mahler and Ady.[24] These observations regarding the inherent limitations of a casting procedure, incorporate a clinical variable unaccounted for in the mathematical models that assume intimate crown to preparation contact. In addition, the castings in the present study were subjected to airborne-particle abrasion. This procedure was performed because it has been clinically recommended[27] before cementation; it provides enhanced retention to the crowns.[2] On the other hand, airborne-particle abrasion may have compromised some of the internal adaptation of the crowns. It is unknown how this may have affected the results in this study.

In this study, the wax was applied directly onto the metal dies. It has been shown that the degree of adaptation or misfit of a crown that has been waxed onto a metal die is less than for a crown waxed on a stone die.[28] Metal dies were used to avoid fracture or distortion of the die during testing. Alternatively, the crowns in the current study could have been duplicated in the form of stone dies and the waxing performed on stone dies.

The rationale for using base metal alloy in this study was its high compressive strength, which allows

**Table III.** Mann-Whitney *U* test for strain gauge measurements

| Pairs compared | Comparison | *P* value |
|---|---|---|
| Control vs mesiodistal grooves | NSD | .165 |
| Control vs mesiodistal boxes | NSD | .190 |
| Control vs buccal-lingual grooves | NSD | .143 |
| Control vs occlusal inclined planes | NSD | .165 |
| Control vs occlusal isthmus | NSD | .579 |
| Control vs reduced TOC | Control < reduced TOC | .003 |
| Mesiodistal grooves vs boxes | Grooves < boxes | .023 |
| Mesiodistal grooves 1 vs buccal-lingual grooves 3 | Mesiodistal grooves 1 < buccal-lingual grooves | .009 |
| Mesiodistal grooves vs occlusal inclined planes | Mesiodistal grooves < occlusal inclined planes | .011 |
| Mesiodistal grooves vs occlusal isthmus | NSD | .971 |
| Mesiodistal grooves vs reduced TOC | Mesiodistal grooves < reduced TOC | <.0001 |
| Mesiodistal boxes vs buccal-lingual grooves | NSD | .796 |
| Mesiodistal boxes vs occlusal inclined planes | NSD | .739 |
| Mesiodistal boxes vs occlusal isthmus | NSD | .165 |
| Mesiodistal boxes vs reduced TOC | NSD | .075 |
| Buccal-lingual grooves vs occlusal inclined planes | NSD | .912 |
| Buccal-lingual grooves vs occlusal isthmus | NSD | .143 |
| Buccal-lingual grooves vs reduced TOC | NSD | .143 |
| Occlusal inclined planes vs occlusal isthmus | NSD | .105 |
| Occlusal inclined planes vs reduced TOC | NSD | .105 |
| Occlusal isthmus vs reduced TOC | Occlusal isthmus < reduced TOC | .011 |

**Table IV.** Mann-Whitney *U* test for universal testing machine measurements

| Pairs compared | Comparison | *P* value |
|---|---|---|
| Control vs mesiodistal grooves | NSD | .280 |
| Control vs mesiodistal boxes | NSD | .105 |
| Control vs buccal-lingual grooves | NSD | .089 |
| Control vs occlusal inclined planes | NSD | .247 |
| Control vs occlusal isthmus | NSD | .796 |
| Control vs reduced TOC | Control < reduced TOC | <.0001 |
| Mesiodistal grooves vs boxes | NSD | .089 |
| Mesiodistal grooves 1 vs buccal-lingual grooves 3 | Mesiodistal grooves < buccal-lingual grooves | .019 |
| Mesiodistal grooves vs occlusal inclined planes | NSD | .105 |
| Mesiodistal grooves vs occlusal isthmus | NSD | .796 |
| Mesiodistal grooves vs reduced TOC | Mesiodistal grooves < reduced TOC | <.0001 |
| Mesiodistal boxes vs buccal-lingual grooves | NSD | .631 |
| Mesiodistal boxes vs occlusal inclined planes | NSD | .739 |
| Mesiodistal boxes vs occlusal isthmus | NSD | .579 |
| Mesiodistal boxes vs reduced TOC | Mesiodistal boxes < reduced TOC | <.0001 |
| Buccal-lingual grooves vs occlusal inclined planes | NSD | .739 |
| Buccal-lingual grooves vs occlusal isthmus | NSD | .315 |
| Buccal-lingual grooves vs reduced TOC | Buccal-lingual grooves < reduced TOC | .011 |
| Occlusal inclined planes vs occlusal isthmus | NSD | .315 |
| Occlusal inclined planes vs reduced TOC | Occlusal inclined planes < reduced TOC | .004 |
| Occlusal isthmus vs reduced TOC | Occlusal isthmus < reduced TOC | <.0001 |

the metal to resist deformation if excessive forces are applied. However, Eden et al[29] has shown that base metal alloys have inferior fit on a metal die. In that study, waxing was performed on metal dies as in the current study. The use of a base metal alloy may be a limitation of this study.

To test the crowns, a recipient site for the tip of the universal testing machine was formed as an extension on the facial surface of the crowns. The projection produced a lever arm that permitted leverage to be transmitted to the crown that would not occur clinically and may compromise the application of these data to a clinical complete coverage crown.

In the original model described by Zuckerman[14] and supported by Parker,[13] the axial-occlusal angle was sharp and had no bevel preparation. The fabrication of the bevel in the present study offered a reduced axial wall height that deviated slightly from the mathematical model described by Zuckerman.

Regardless of the inherent limitations of any casting procedure or technical modifications that could offer an improved internal adaptation, there will always be a space between a crown and a die. This space will be occupied by the cement. Based on this observation, multiple authors[10,12,29] have indicated that this film of cement is the key to determining the resistance of a crown.

In a computer study, Wiskott et al[25] demonstrated that the axis of rotation in resistance is not at the crown margin but resistance to lateral dislodgement is a function of the distribution of compressive force vectors acting on the cement interface. Wiskott et al[12] indicated that the limiting taper theory developed by Parker[13] as a mathematical model may not be valid since a linear relationship was found between the occlusocervical dimension of the axial wall and the diameter of the tooth preparation. Weed and Baez[10] found a high linear relation between the total occlusal convergence of a crown preparation and the corresponding resistance. Wiskott et al[26] confirmed the fact that the compressive strength of the cement is the parameter that determines the amount of resistance of a specific preparation design.

## CONCLUSIONS

Within the limitations of this study, the following conclusions are offered relative to the effectiveness of several tooth preparation modifications on the resistance form of teeth prepared with 2.5 mm of occlusocervical dimension, 20 degrees of TOC, and an occlusocervical/faciolingual dimension ratio below 0.4.

1. Decreasing the TOC from 20 to 8 degrees in the apical 1.5 mm of the reduced axial surfaces significantly increased resistance form.

2. Two proximal grooves or 2 proximal boxes or 2 grooves (mid-buccal and mid-lingual) that followed the existing convergence of the axial walls (20 degrees) did not significantly enhance resistance form.

3. Preparing the occlusal surface so it possessed inclined planes that paralleled the original inclined form of the occlusal surface (30 degrees relative to the long axis of the tooth preparation) did not significantly enhance resistance form.

4. Preparing an occlusal isthmus 1 mm deep and 1.5 mm wide did not significantly improve resistance form.

5. The most effective method of enhancing resistance form in a tooth preparation that lacks resistance is to decrease the total occlusal convergence of the cervical portion of the prepared axial walls.

## REFERENCES

1. Academy of Prosthodontics. Glossary of prosthodontic terms. 7th ed. J Prosthet Dent 1999;81:96.
2. Jorgensen KD. Relationship between retention and convergence angle in cemented veneer crowns. Acta Odontol Scand 1955;13:35-40.
3. Kaufman EG, Coehlo DH, Colin L. Factors influencing the retention of cemented gold castings. J Prosthet Dent 1961;11:487-502.
4. Lorey RE, Myers GE. The retentive qualities of bridge retainers. J Am Dent Assoc 1968;76:568-72.
5. Reisbick MH, Shillingburg HT Jr. Effect of preparation geometry on retention and resistance of cast gold restorations. J Calif Dent Assoc 1975;3:51-9.
6. Woolsey GD, Matich JA. The effect of axial grooves on the resistance form of cast restorations. J Am Dent Assoc 1978;97:978-80.
7. Potts RG, Shillingburg HT Jr, Duncanson MG Jr. Retention and resistance of preparations for cast restorations. J Prosthet Dent 1980;43:303-8.
8. Kishimoto M, Shillingburg HT Jr, Duncanson MG Jr. Influence of preparation features on retention and resistance. Part II: Three-quarter crowns. J Prosthet Dent 1983;49:188-92.
9. Owen CP. Retention and resistance in preparations for extracoronal restorations. Part II: Practical and clinical studies. J Prosthet Dent 1986;56:148-53.
10. Weed RM, Baez RJ. A method for determining adequate resistance form of complete cast crown preparations. J Prosthet Dent 1984;52:330-4.
11. Wiskott HW, Nicholls JI, Belser UC. The relationship between abutment taper and resistance of cemented crowns to dynamic loading. Int J Prosthodont 1996;9:117-39.
12. Wiskott HW, Nicholls JI, Belser UC. The effect of tooth preparation height and diameter on the resistance of complete crowns to fatigue loading. Int J Prosthodont 1997;10:207-15.
13. Parker MH, Malone KH 3rd, Trier AC, Striano TS. Evaluation of resistance form for prepared teeth. J Prosthet Dent 1991;66:730-3.
14. Zuckerman GR. Resistance form for the complete veneer crown: principles of design and analysis. Int J Prosthodont 1988;1:302-7.
15. Eames WB, O'Neal SJ, Monteiro J, Miller C, Roan JD Jr, Cohen KS. Techniques to improve the seating of castings. J Am Dent Assoc 1978;96:432-7.
16. Ohm E, Silness J. The convergence angle in teeth prepared for artificial crowns. J Oral Rehabil 1978;5:371-5.
17. Mack PJ. A theoretical and clinical investigation into the taper achieved on crown and inlay preparations. J Oral Rehabil 1980;7:255-65.
18. Nordlander J, Weir D, Stoffer W, Ochi S. The taper of clinical preparations for fixed prosthodontics. J Prosthet Dent 1988;60:148-51.
19. Trier AC, Parker MH, Cameron SM, Brousseau JS. Evaluation of resistance form of dislodged crowns and retainers. J Prosthet Dent 1998;80:405-9.
20. Teteruck WR, Mumford G. The fit of certain dental casting alloys using different investing materials and techniques. J Prosthet Dent 1966;16:910-27.
21. Kono A, Fusayama T. Casting shrinkage of one-piece-cast fixed partial dentures. J Prosthet Dent 1969;22:73-83.
22. Fusayama T, Ogata K. Casting shrinkages of inlay golds of known composition. J Prosthet Dent 1966;16:1135-43.
23. Morey EF. Dimensional accuracy of gold alloy castings. Part 2. Gold alloy shrinkage. Aust Dent J 1991;36:391-6.
24. Mahler DB, Ady AB. The influence of various factors on the effective setting expansion of casting investments. J Prosthet Dent 1963;13:365-73.
25. Wiskott HW, Belser UC, Scherrer SS. The effect of film thickness and surface texture on the resistance of cemented extracoronal restorations to lateral fatigue loading. Int J Prosthodont 1999;12:255-62.
26. Wiskott HW, Krebs C, Scherrer SS, Botsis J, Belser UC. Compressive and tensile zones in the cement interface of full crowns: a technical note on the concept of resistance. J Prosthodont 1999;8:80-91.
27. Goodacre CJ, Campagni WV, Aquilino SA. Tooth preparations for complete crowns: an art form based on scientific principles. J Prosthet Dent 2001;85:363-76.
28. Fusayama T, Ide K, Kurosu A, Hosoda H. Cement thickness between cast restorations and preparation walls. J Prosthet Dent 1963;13:354-64.
29. Eden GT, Franklin OM, Powell JM, Ohta Y, Dickson G. Fit of porcelain fused to metal crown and bridge castings. J Dent Res 1979;58:2360-68.

*Reprint requests to:*
DR PERIKLIS PROUSSAEFS
SCHOOL OF DENTISTRY/LOMA LINDA UNIVERSITY
CENTER FOR PROSTHODONTICS AND IMPLANT DENTISTRY
LOMA LINDA, CA 92350
FAX: (909) 558-4803
E-MAIL: pproussaef@hotmail.com

0022-3913/$30.00


doi:10.1016/j.prosdent.2003.10.005