ABSTRACT

Title of Thesis: The effect of grooves on the load to dislodgement of Procera crowns

Monica Parekh, DMD, Master of Science, 2011.

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Statement of Problem: The objective of this study was to investigate the effect of grooves on a tooth preparation for a full coverage zirconia Procera restoration on the load to dislodgement of Procera zirconia crowns.

Methods: Three standardized stainless steel dies were used to simulate a mandibular molar crown preparation with inadequate retention and resistance forms. The first die resembled a preparation with no grooves (control). The second die resembled a preparation with two grooves placed on the mid-mesial and distal walls. The third die resembled a preparation with two grooves as above; however, the grooves were placed after the dies were scanned. The stainless steel dies were scanned to fabricate zirconia abutments. After the addition of porcelain to the copings, the crowns were cemented with zinc phosphate cement. The load to dislodgement was tested via a universal load-testing machine. Data was analyzed using a one-way ANOVA statistical test followed by Tukey’s HSD test.

Results: There was a significant difference between the three experimental conditions ($F = 213.69$, $p < 0.0001$). Procera crowns cemented on the stainless steel dies with grooves prepared before scanning had a significantly higher load to dislodgement than all other groups (3850 ± 370 N). Procera crowns cemented on the stainless steel dies with grooves prepared after scanning exhibited the second highest load to dislodgement (2610 ± 250 N). The lowest value of load to dislodgement was when no grooves were present (2260 ± 300 N).

Conclusion: Grooves placed before scanning of dies provided the most improvement load to dislodgement of Procera zirconia crowns.

The effect of grooves on the load to dislodgement of Procera crowns

By:

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Thesis submitted to the faculty of the Graduate School
of the University of Maryland Baltimore in partial fulfillment
of the requirements for the degree of
Master of Science
2011

Dedication

This thesis is dedicated to my parents in appreciation for all the support they have provided me through my education, career, and life.

Acknowledgments

I would like to give a special acknowledgement to my mentors. My thesis committee members, Dr. Radi Masri, Dr. Carl F. Driscoll, Dr. Elaine Romberg and Dr. Guadalupe Garcia offered me the exceptional guidance and knowledge to complete this thesis.

I would also like to acknowledge Ms. Roseanna Morgan for her assistance in obtaining the equipment and material for this research.

A special thanks goes to my co-residents at the University of Maryland, Baltimore, who have helped in the completion of the thesis.

Lastly, I would like to thank the contribution from the American Academy of Fixed Prosthodontics for providing the Tylman Grant Research Fellowship Awards in 2010.

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1 INTRODUCTION

1.1 *Principles of tooth preparation*

As we age, our teeth begin to wear, become carious, or become unhealthy overtime, requiring a full coverage crown on the tooth. Possible instances for when a crown is needed include an area of decay that is too large that a mere filling is not enough; a significant amount of wear that the patient's occlusal vertical dimension needs to be challenged and restored; an unesthetic tooth based on its position, color, or size. If prepared and restored correctly, crowns are excellent restorations because they protect the remaining structure of the tooth and increase its strength in a functional oral cavity. Some important factors that help in the function, esthetics, and longevity of crowns include features of the tooth preparation; namely: the retention and resistance form of the tooth preparation. Retention is the quality inherent in the dental prosthesis—in this instance, a crown—acting to resist forces of dislodgement along the path of placement [1]. The resistance form is that feature of the tooth preparation that allows the crown to resist dislodgement along an axis other than the path of placement [1].

As stated by Gilboe and Teteruck, there are principles and factors that are necessary to obtain adequate retention and resistance form in a tooth preparation including: a) minimum taper of opposing walls, b) long axial walls, and c) adequate surface area. The main contributor to the retention and resistance of a crown are the axial surfaces of the tooth preparation. This is created by appropriate taper – the convergence of two opposing external walls of a tooth preparation as viewed in a given plane [1]. Secondary factors include the presence of grooves, boxes, pinholes, or any combination of the three. To prevent the dislodgement of the restoration during function, these factors must be incorporated into the preparation design, allowing retention to counteract tensile stress and resistance to oppose shearing stress. Any particular tooth may have variations in the taper and overall preparation design contributing to the retention and resistance form. The optimal means in gaining effective retention and resistance form is via minimal occlusal convergence of the axial walls. Taper of the preparation may exceed 5 degrees only if adequate length is present [2].

1.2 *Factors that influence retention*

A study was conducted on the relationship between retention and convergence angle in cemented crowns by Jorgensen. Cones of galalith with an 8 mm base and an 8 mm height and variable convergence angles of 5, 10, 15, 20, 25, 35, or 45 degrees were used. The cones were made on a lathe, leaving a dull surface without visible marks. For each convergence angle, 10 cones were made. Brass caps were used as the restorative material and were cemented using zinc phosphate. The retention between oblique surfaces of the cone and cap were tested 24 hours post cementation via pull test. The results were plotted on a graph, creating a hyperbolic relationship. The retention of a crown drops sharply when the convergence angle is greater than 20 degrees. The surface roughness was also tested by scratching the intaglio surface of the brass cap. It was found that when compared to its corresponding unscratched cap, there was a significant increase in the amount of retention. However, there can be no specific relationship determined because the roughening of the brass caps was not standardized [3].

According to Kaufman, there are six factors involved with tooth preparation that can influence retention. These variables include: a) surface area, b) height of prepared surfaces, c) convergence angle, d) surface texture of the tooth, e) the presence of intracoronal retentive devices in the preparation, and f) the degree of retention provided by various components of the prepared area [4]. Kaufman's conclusions were based on a study conducted on cemented gold castings. Dies made of aluminum alloy of constant resiliency, tensile strength, and surface textures were used. The height of the aluminum dies varied: 4, 7, and 10 mm. He found that an apparent increase in retention occurred as the height and parallelism of the axial walls increased. However, if the degree of convergence was the same, regardless of the height of aluminum dies, the castings embodied the same retentiveness. The amount of retention was determined based on measuring the load to dislodgement. Based on the diameter increments increases of 0.025 inch and surface area increases of 0.22 sq. inch, retention increased linearly as the diameter of the aluminum die increased. He also found that the greater parallelism of the axial walls, the greater difficulty encountered upon cementation due to the incomplete seating of crowns. Kaufman suggested that perforations in the occlusal surface, also known as planned openings, of some of the castings improved seating. A planned opening in the casting was important for the escape of excess cement. Not only did this allow for proper seating of the restoration, but it also allowed for a greater ease of placement and an increase in retention by 19% to 32% [4].

Kaufman also stated that there was an increase in retention as the height and diameter of the crown preparation increases. Clinically, an ideal height and diameter may not be possible due to the amount of tooth structure remaining, the location of the tooth itself, the location of teeth adjacent and opposing the prepared tooth, and the amount of soft tissue and bone surrounding the preparation. Therefore, this study has some drawbacks. It is rare to find a tooth preparation that is 7 or 10 mm in height. Furthermore, the idea of planned perforations is good but it is not clinically relevant and should not be practiced routinely. Perforating the occlusal surface of the crown will reduce the strength of the crown and increase the potential for micro leakage and potential failure of the crown. Therefore, to help release the hydraulic pressure created, it is prudent to use die spacer in fabrication of the crown and to slightly rotate the crown upon seating as recommended by Marker.

In agreement with the Kaufman findings, Marker found that the preciseness and degree of taper of prepared tooth surfaces, the accuracy and adaptability of the casting, and the cementing procedure affect the degree of retention of a dental casting. In Marker's study, 13 different clinicians received identical quadrant models of ivory teeth with standard preparations. Clinicians made two sets of die stone and castings using whatever materials they preferred, but including die spacer in one of the sets. Pre- and post-cementation frictional measurements were recorded. Mean retention loads were also measured after the cementation for the unspaced and spaced castings. Using die spacer allowed for better seating of the castings because it allowed for better flow of the cement. There was an increased retention observed in 55% of castings with die spacer. Die spacing techniques reduced retention of castings before cementation but allowed for a better fit and increased retention after cementation. It was also found that a roughened surface helps increase retention with the application of zinc phosphate cement [5]. Applying die spacer is still used commonly and is recommended during fabrication of restorations.

Zuckerman added to these concepts. He examined and discussed the fundamental physical phenomenon of the retention of a complete crown. He separated it into five major factors: 1) abutment length, diameter and surface area, 2) convergence of axial walls, 3) auxiliary boxes, grooves and pins, 4) amount of crown coverage, as well as 5) type of cement [31].

Wilson attempted to validate the inverse relationship between preparation convergence and crown retention using brass dies. It was found that there was a significant difference in the retention of crowns with different convergence angles; however, this relationship was not completely inverse. Maximum retention did not occur at 0º convergence, but peaked between 6º and 12º. Beyond 12º convergence, the rate of retention loss was approximately 0.25MPa per degree [32].

The synopsis of these studies shows that retention is dependent upon several factors with the most critical being parallelism of the axial walls. They also demonstrate that less total convergence and taper influences retention positively. An adequate height and width (e.g. surface area) also improves the retention of a restoration.

1.3 *Factors that influence resistance*

Resistance form is a necessity to tooth preparation for the survival of a full coverage restoration. An effective method of testing the resistance form of a crown preparation is by attempting to roll an uncemented casting or wax pattern off of the die in every direction. If there is an opposition to dislodgement, the resistance of the preparation is clinically acceptable [6].

Parker presented a mathematical formula to determine an acceptable resistance form based on the amount of taper in the preparation. When a crown is rotated off a tooth, it forms an arc. If the direction of the arc is towards the tooth, resistance is present; however, if the pivoting point is not directly penetrating the tooth, there is no resistance form. Resistance also has a unique property of either being present or absent. Therefore, resistance has an "on-off" nature. An efficient manner in determining whether a preparation has resistance is by comparing the slope to the direction of the arc of resistance. It has been found that "any slope of the preparation more shallow than its arc will not have resistance and any slope steeper than the direction of arc will have resistance"[6].

Determined by the direction of the arc, it is helpful to be aware at what taper the resistance form turns from on to off, described by Parker as the limiting taper. Any taper less than the limiting taper will provide resistance form and any taper greater than the limiting taper will turn the resistance off, providing the clinician with a quantitative boundary to ensure resistance. When considering each point on a preparation, Parker found that the limiting taper depends on the height to base ratio (H/B) of the preparation [6].

Parker et al thought it was necessary to create a valid standardization for minimum taper since it is difficult to clinically achieve a 2-5 degree taper. Parker also created other guidelines that govern the resistance form of a tooth preparation. These guidelines involved the entire preparation to determine the appropriate resistance [7]. Parker described an exact dividing point between the on and off resistance, which is the proposed standard as minimally acceptable taper. Therefore, with incisors and canines, the height (H) is usually greater than the base (B); and a 29 degree taper is acceptable as minimum for incisors and 33 degrees for canines on average. Bicuspids may range from 10-30 degrees and with molars, an 8.4 degree taper is allowed using a normal range of H/B. It should be kept in mind that Parker found these numbers to be minimally acceptable. There are still many variations a tooth may have so depending on factors such as tilt, a 45 degree taper may be clinically acceptable as for others, not even a 0 degree taper is adequate [7].

Mack conducted a study to find if it is possible to observe tapers of 5 degrees intraorally. A laboratory investigation was used to assess the angle of the taper at which the dentist is able to confirm the plane and lack of undercuts. The limitations were found in the individual variations of tooth size, dentist to tooth distance, and individual variations in visual acuity. Therefore, for this particular study, these limiting factors were standardized. Monocular and binocular vision was tested. The dentist to tooth distances included 25 cm, 35 cm, and 45 cm. The results showed that monocular vision allowed for finer taper visualization than does binocular therefore less undercuts were produced under monocular vision. Finer tapers were also best visualized from the greatest distance in combination with accurate vision. At a 15cm distance, the average angle of taper was 5 degrees; at 35 cm, a 4 degree taper was visualized; and at 45cm, the average taper was 3 degrees [8].

Hegdahl and Silness studied variations in the resisting areas for different types of complete crown preparations. Conical and pyramidal preparations were used. They determined that resisting areas are larger in pyramidal than conical preparations. Therefore when preparing teeth for complete crown restorations, one should avoid excessive rounding of axial angles. They also contended that the use of large convergence angles results in small resisting areas and should be avoided. It should also be noted that too little taper must be avoided as well because of the difficulties encountered with cementation. Lastly, a relatively large reduction in resisting areas is observed in preparations that combine large diameters and large convergence angles [9].

The analysis of Gilboe and Teteruck with adequate length, surface area, and parallelism and Parker with the definition of limiting taper to distinguish an “on” or “off” resistance will indicate whether a tooth preparation embodies a resistive form. Resistance form is thought to be a more fundamental characteristic; therefore, if a preparation has resistance form, it will be retentive in nature [10].

To summarize, resistance form has been described by using mathematical formulas, an average number in general, and as a basic concept. It can be agreed upon that resistance form is best created with parallelism and minimal taper. Evidence supports that resistance is one of the most essential elements in a crown preparation design to ensure clinical success. Although the on/off concept theorizes a minimal acceptable taper, clinical observations are necessary to decide whether resistance form is achievable or not and supersedes the formula. Finally, because molars tend to have a small height to base ratio, it may be challenging to obtain resistance form.

1.4 *Methods of enhancing retention and resistance form*

Clinically, many of the teeth prepared to receive full coverage restoration lack the necessary retention and resistance form and therefore, it may be necessary to enhance the preparation design. If the basic tooth preparation lacks the proper parallelism, length, and surface area, its retention and resistance form will be sub-par dooming the restoration for failure. To enhance the basic principles of tooth preparation, secondary factors can be incorporated such as grooves, pins, and boxes. Grooves best augment resistance form while conserving the maximum amount of tooth structure. A box is similar to a groove, only with increased surface area [2]. A pinhole contributes more to retention because it is directly related to the area of the pin contacting the tooth. Therefore, the length and diameter of the pin are important issues. A groove, box or pinhole must be located with the line of withdrawal, as far as possible from its reciprocal retentive feature, and at a point that permits a maximal length [2].

The definition of a groove as stated by GPT-8 is a long narrow channel or depression, such as the indentation between tooth cusps or the retentive features placed on tooth surfaces to augment the retentive characteristics of crown preparations [1]. Gilboe and Teteruck categorized groove placement as a conservative secondary factor in tooth preparation to enhance retention and resistance. To obtain optimum tooth preparation, there are ideal numbers and methods to create a resistive and retentive crown preparation; however, there can be complications creating a situation that is not adequate. It is difficult to clinically prepare a taper of 2-5 degrees. Also, depending on the nature of the tooth, there may not be adequate tooth structure to sustain a proper length and surface area. Therefore, the placement of grooves aids in increasing the retention and the resistance of a tooth preparation [4].

Considering that groove placement is a secondary factor in retention, it is reasonable to assume that the addition of grooves to a tooth preparation will increase the surface area of the preparation, allowing for better retention. In a study conducted by

Bowley, the amount of surface area improvement was evaluated with the use of supplemental grooves in tooth preparations with unfavorable retention form. A right regular pyramid simulated a mandibular molar tooth preparation with variable taper of 2 to 25 degrees and height of 3 or 4 mm. Via geometric formulas, the surface area of each pyramid was calculated. Using a tapered fissure bur, conical shaped grooves and boxes of varying number and sizes were incorporated to the design. The researchers determined whether the surface area was lost or gained. Significant values of surface area increase were detected in the 4mm height grouping. In the 25 degree level with 4 grooves, a 35.2% gain was found. It was concluded that axial-wall groove and box introduction did improve the surface area of poorly retentive preparations [11].

Emara conducted another study that examined whether the placement of grooves actually affects the retention and resistance. The researchers were concerned that if there is a lack of retention and resistance form in clinical preparation of teeth for resin-bonded retainers, a clinical failure will occur. Ivory teeth were used to simulate maxillary and mandibular right second molars. They were prepared for resin-bonded retainers and metal dies were made. Two vertical grooves, on the mesial and distal surfaces were prepared 0.5 mm occlusally from the finish line and 0.5 mm palatal to the most facial extent of the proximal surface in the ivory teeth. The grooves were placed parallel to the facial curvature of the teeth creating an angle of 10 degrees between the grooves and long axis of the tooth. The restoration was cemented to the metal replica using Panavia EX. Upon loading, forces were directed to the long axis of the tooth to test the retention and resistance in vertical displacement. The groove placement resulted in a substantial increase in debonding forces for maxillary molars. For mandibular molars, the effect of the grooves was less pronounced. It was also an interesting finding that the maxillary molars had greater resistance to dislodgement than the mandibular when both did not have grooves. Upon discussion, the researchers felt the convergence angle of the mandibular molars was greater and the length of the grooves was insufficient [12].

Witwer discussed the effects of surface texture and grooving on the retention of cast crowns. Twenty freshly extracted mandibular third molars were collected with their roots embedded in acrylic blocks. The teeth were prepared with a 34 mm circumference, 5 mm occlusal height, and a chamfer and bevel margin. After impression making and die fabrication, base metal cast crowns were made. In 10 of the crowns, a 0.5 mm deep circumferential groove was cut on the internal surface of the crowns. Five plain and five grooved crowns were cemented using zinc phosphate and the remaining set of plain and grooved crowns were cemented using zinc polycarboxylate cement. After 24 hours, the tensile strength was tested. The test was repeated with finely smoothed tooth preparations. Witwer found that there was no significant difference in the retention of plain crowns luted to the teeth with either cement. The tensile load failure for ungrooved crowns luted to rough finished teeth was significantly greater. Visual inspection of crowns after failure showed that zinc polycarboxylate cement was retained within the cast crown. The zinc phosphate cement was found on both the clinical and cast crowns, however more was found in the grooved cast crowns. He concluded that placing grooves on a cast crown is not necessary if the crown is cemented with zinc polycarboxylate cement on a rough tooth preparation. In contrast, if zinc phosphate cement is used as the luting agent, optimum cast retention will occur with grooved crowns and a smooth tooth surface finish [13].

In a study designed by Woolsey and Matich, the effect of parallel axial grooves on the resistance form of cast restorations was demonstrated. Stainless steel dies of 5, 10, and 15 degree tapers and 3, 4, 6, 8, and 10 mm lengths were machined. With the exception of the taper and length, duplicate gold castings were created with one continuous slope of 45 degrees to simulate the vector formed by the vertical and horizontal components of mastication. Each die and restoration was subject to vertical load. Inadequate resistance form resulted in the vertical load pin moving down the occlusal slope, forcing the casting off the die. In instances with proper resistance form, the casting remained seated on the die and the pin impressed the occlusal slope at the contact point.

After determining which preparation did not have adequate resistance form (3 and 4 mm length and 10 and 15 degree taper), the dies were modified. Grooves that were 1 mm wide, 1 mm deep and 1 mm short of the finish line were placed in either the proximal surfaces or the buccal and lingual surfaces. Since there was no dislodgement observed with groove placement, a positive effect of placing parallel axial grooves on the resistance form of crown preparations was noted [14].

With the conclusions of these studies, using grooves to enhance retention and resistance form is an effective method. In clinical practice today, it is common to place grooves on a tooth preparation to ensure that a restoration will not dislodge due to a lack of resistance form.

1.5 *Location of groove placement*

The specific area on the tooth where a groove is placed can contribute to the retention and resistance form. Woolsey and Matich determined that the placement of grooves on the buccal and lingual surfaces of teeth maximized retention but only provided partial resistance. However, resistance form was maximized with interproximal grooves due to the opposition of the bucco-lingual component of masticatory forces [14].

In Shillingberg's textbook: Fundamentals of Fixed Prosthodontics, he explains that the most commonly used feature to compensate for retention is the proximal groove. To achieve maximum effectiveness, grooves must have definite lingual walls. It is possible to develop a resistance to torques by producing a "lingual hook" and a "lock effect." This means directing the bur and groove slightly to the opposite corner of the tooth. If the groove is directed buccally instead of lingually, the buccal plate of the enamel will be undermined. The placement of grooves too far lingually will result in lessened resistance, although it will have little effect on retention [15].

The main reason for crown displacement is that the features of the tooth preparation do not counteract the forces directed against the restorations. Shillingburg, Potts, and Duncanson investigated different geometrical preparation designs on retention and resistance of partial and complete veneer crowns. Axial grooves were placed on a three-quarter crown and a seven-eighths crown and were tested against a three-quarter crown, seven-eighths crown, and a complete crown without grooves. Retention values with the addition of grooves did not show statistically significant differences because according to them, the placement of grooves has little to do with increasing total surface area. However, resistance values significantly increased with a placement of grooves or extending axial coverage. Any preparation feature that opposes dislodgement of the restoration by external forces increases resistance, and proximal groove placement provides for this feature. However, retention did increase when comparing groove preparations from the three-quarter crown to the complete coverage crown without grooves. Proximal grooves do increase resistance because they shorten the arc that the restoration can rotate off of the preparation [16].

In Parker's study of resistance and limiting taper, they determined at what point in the preparation was most likely to have the least resistance. They also indicated that most teeth will rotate off the tooth mesially [6]. Therefore, the best location for groove placement is where it makes the limiting taper as great as possible. The ideal location is more coronal and closer to the center of rotation of the preparation. This creates an intersection of the arc of rotation and the wall of the groove and therefore prevents dislodgement. Thus, since the mesial wall is affected the most by negative limiting taper, grooves should be placed on the buccal and/or lingual walls of the tooth preparation [6].

Groove placement is important to maximize the resistance form, since that is the reason a groove is used. It is most effective and common practice to place the grooves interproximally because it shortens the arc of rotation for the restoration to dislodge from.

1.6 *Groove Design*

Several studies were also conducted on the style of groove created. Kishimoto and Shillingburg tested v-shaped grooves versus round grooves versus proximal boxes on three-quarter crowns on resistance and retention. A nickel-chrome die with 6 mm in length and 6 degree taper was made with either two round proximal grooves in the lingual half of proximal surfaces, two V-shaped proximal grooves, four round proximal grooves, and two proximal boxes. Retention was tested via removal of the casting by tensile force and resistance was measured by displacement via compressive force. The greatest retention was seen in preparations with multiple grooves or where boxes were present (avg. load 175 lbs. and 181 lbs. respectively) while V-shaped grooves only had an average load of 72 lbs. Round grooves and proximal boxes were markedly superior to v-shaped grooves in resistance form (avg. load 1,292 lbs. vs. 723 lbs.) [17].

Tjan defined two types of groove-flare designs. Type I is described as a fishhook design placed into the dentin and directed to the center of the tooth. Disadvantages of this type of groove is that it is more technique sensitive because if the groove is placed too deep it may endanger the vitality of the tooth especially if placed mesially. The type II groove is placed in the dentin parallel to a line tangent to the outer convexity of the tooth surface. In this type, there is minimal endangerment to the pulp. A biogeometric guide was created to determine the topography of groove placement based on histologic characteristics of a tooth, and the mechanical and structural requirements of the preparation design. The biological considerations include the size and location of the pulp chamber, the thickness of the enamel, the direction of the enamel rods, the alignment of the tooth involved, and the physical properties of the dental structure. The mechanical function includes the resistance and retention of the preparation and the optimal size and length of the grooves. To create ideal groove characteristics, Tjan suggested using a tapered fissure carbide bur to help maximize the length to about 0.5 mm short of the gingival margin. Other recommendations included a definite seat, placed parallel to the path of withdrawal, placed parallel to the cingulum wall for anterior teeth, and a groove-offset should be present for sufficient bulk to provide strength [18].

Proussaefs studied the effectiveness of auxiliary features on a tooth preparation with inadequate resistance form. An ivory tooth was prepared with a 20 degree total occlusal convergence, 2.5 mm height, a shoulder finish line and grooves on the direct mesial and distal surfaces. Cast metal crowns were fabricated and resistance form was tested by applying force at a 45 degree angle in a buccal to lingual direction. They determined that grooves placed on a crown preparation that originally had a reduced resistance form was not effective in increasing the resistance form. The only modification that enhanced the resistance form was reducing the total occlusal convergence in the cervical half of the axial wall. The researchers believe that the grooves would have been effective if the total occlusal convergence were less than 20 degrees. It was also found that there was an increased gap and loss of adaptation between the die and the crown, especially in the cervical area of the preparation [19].

In today's practice, grooves are round and created by a tapered fissure bur. It is best to make the grooves as parallel as possible to the path of withdrawal to make the seating of the crown possible. Grooves should also be placed 0.5 mm short of the margin to ensure that the margin does not get disfigured and the crown will have a tight marginal seal. However, depending on the preparation of the tooth, the guidelines may be modified.

1.7 *Grooves and complete crown seating*

Additional reasons a crown may lack adequate retention form is if there is a short clinical crown, a malformed, or a malpositioned tooth. Chan studied the effect of cement keys by placing grooves on complete crowns with good and poor retentive qualities. Gold crowns were prepared for extracted human teeth with either a 7 degree or 30 degree tapered wall. Auxiliary retention was provided by either one groove in the crown, one groove in the tooth, opposing grooves in the crown and tooth, or no grooves. For the teeth with a 30 degree taper, no groove placement had similar retention to one groove placement (12 kg). Opposing grooves allowed the retention to double (22kg). With the 7 degree tapered teeth it was found that placing a groove in the crown was more retentive than placing it in the tooth. Also, the opposing grooves allowed the strength to nearly triple (42 kg vs. 132 kg). It was concluded that cement keys do increase retention in preparations, especially when placed in opposition to the tooth and crown [20].

1.8 *Complications of grooves*

Tjan studied how grooves may also increase complications of crown seating and marginal fit. When cementing cast metal crowns, it is common to find hydraulic pressure developing, making it more difficult to seat the crown completely. It became common practice to rock the crown while seating it to reduce the pressure. However, with the placement of grooves, there can be only a single path of insertion. Therefore, placing axial grooves further complicates the seating and cementation process. In the study, prepared ivory teeth 6mm in height and 13 degree total occlusal convergence were used. They were divided into 3 groups: 1) no groove placement, 2) 2 grooves, one on each mesial and distal wall, 3) 4 grooves, one on each buccal, lingual, mesial and distal wall. Once cemented, the vertical or gingival discrepancy was measured by determining the thickness of the cement. Results showed that placing grooves in the preparation adversely affected the seating of full cast gold crowns. The vertical opening found was 185 microns, 270 microns, and 278 microns, respective to the groups. It was concluded that groove placement increases the amount of hydrostatic pressure created upon cementation [21].

1.9 *Retention and Cement factors*

El-Mowafy examined the effect of preparation taper and height on the retention of crowns using resin cements. Initially, natural tooth preparations with 12º ± 2º and 35º ± 2º were cemented with zinc phosphate and two different systems of resin cement. Crowns cemented on preparations with the convergence angles of 12º ± 2º had a significantly higher retention than those cemented on preparations with convergence angles of 35º ± 2º. Then the retentive values of the cemented crowns were examined on tooth preparations with two different heights: 3 ± 0.25mm and 5 ± 0.25mm. Preparations with greater height were significantly more retentive. Also, crowns cemented with resin cements had greater retentive values than those cemented with zinc phosphate when preparation taper and height were constant. Crowns cemented on preparations with poor convergence angles and heights with resin cement were still more retentive than those cemented on ideal preparations with zinc phosphate cement [36].

Zidan also studied the effect of cement type on the retentive strength of crowns cemented on preparations with different tapers. Crowns were cemented onto preparations with convergence angles of 6º, 12º and 24º with zinc phosphate, glass ionomer and two different adhesive resin cements. Both resin cements produced significantly higher retentive strength than zinc phosphate and glass ionomer cements. It was found that preparations with 6º and 12º taper were significantly more retentive than preparations with 24º taper for all cements [37].

Lorey discussed the effect of varying surface areas of preparations to the retentive strength of a cemented metal casting. The different preparation designs used include complete crown, three-quarter crown, and pinledge retainer which showed differences in the total retentive surface area. It was found that the retention of the casting increased with a corresponding increase in the surface area of the preparation using zinc phosphate cement [38].

Felton tested surface roughness and retention on cemented metal castings. Thirty teeth were prepared using either carbide or diamond burs, thus providing varying surface roughness. Using zinc phosphate cement, the results of the tensile test indicated that teeth prepared with diamond burs had 31% greater retention than preparations made with carbide burs due to the inherent roughness of diamond burs [33].

Ayad found contradicting results. Crowns cemented with zinc phosphate on preparations finished with carbide burs had 46% greater retention than preparations finalized with diamond and 55% greater than finishing burs respectively. The carbide burs prepared a rougher surface finish than those prepared by diamond and finishing burs [34].

1.10 *All-Ceramic restorations*

In 1967, McLean introduced the concept of all-ceramic restorations as a high-alumina ceramic (Al_2O_3) was used in the fabrication of all-ceramic fixed partial denture pontics [22]. Throughout the years, improvements have been made on the mechanical, physical, and chemical properties of all-ceramics, allowing them to be stronger and more predictable [23].

The survival of a dental ceramic restoration is controlled by its density, severity, and the location of critical flaws. Cracks and voids in the ceramic will propagate the failure of the all-ceramic restoration. These factors increase stress and reduce the strength and durability of a ceramic restoration. Tinschert analyzed the distribution of flexural strength values for several ceramics. Six core materials and two veneering ceramics were tested. Among these, the zirconia core proved to have significantly higher mean fracture strength of 913.0 MPa as compared to all the other materials. Dental ceramics should not be solely characterized by the fracture strength, however this investigation proved that zirconia is more suitable for versatile uses within the oral cavity as a core material for all-ceramic restorations [23].

Alumina and zirconia have a higher crystalline content with aluminum oxide and zirconium oxide which demonstrates more favorable mechanical properties. Aluminum is a silvery white, ductile member of the boron group of elements. It is remarkable for its ability to resist corrosion and its low density. Alumina or aluminum oxide is an amphoteric oxide of aluminum with the chemical formula of Al_2O_3. Metallic aluminum is highly reactive with atmospheric oxygen, and a thin passive layer of alumina quickly forms on any exposed aluminum surfaces. This prevents any further oxidation from occurring. The properties of alumina include a relatively high thermal conductivity, insolubility in water, a high level hardness and stability. The oxidation layer created enhances the hardness [24].

Zirconium is a lustrous gray white strong transition metal that resembles titanium. Zirconia is a white crystalline oxide of zirconium. Pure ZrO_2 has a monoclinic crystal structure at room temperature and transitions from monoclinic to tetragonal and cubic at increasing temperatures. The transformation of zirconia induces a large stress and will cause it to crack upon cooling. Therefore, in dental zirconia, yttrium oxide is added to help stabilize the tetragonal and cubic phases. In a stabilized state, if stress is applied and a crack propagates, the tetragonal phase will convert to monoclinic, placing the crack in compression. This retards the growth of the crack and enhances the fracture toughness. This process is known as transformation toughening.

With the positive attributes of both these ceramics, Nobel Biocare created a Procera AllCeram and Procera AllZirkon system (Procera AllCeram; Nobel Biocare, Yorba Linda, Calif). In this system, the alumina and zirconia metals are used as copings and an appropriate veneering ceramic is applied to fabricate the restoration.

1.11 ***The use of grooves in preparations for ceramic crowns***

The studies mentioned above about groove placements have been performed on cast metal and porcelain fused to metal crowns, but not on ceramic crowns. With the increased use of ceramic crowns, especially Procera, for posterior teeth, we assume that the same principles hold. It is unclear how grooves affect the retention of Procera crowns. The dental profession demands restorations that have good strength, color stability, wear characteristics similar to enamel, and a precision of fit while still remaining cost-effective to the patient, clinician, and dental technician [25]. The initial Procera system used titanium copings to create crowns and fixed partial dentures. In

1983, with the advent of alumina and zirconia, there has been an explosion in the use of Procera crowns manufactured by Nobel Biocare (Zurich, Switzerland).

Recommended preparation guidelines for Procera include 2 mm occlusal reduction, 1.5 mm axial reduction, and a chamfer finish line. Sharp line angles such as grooves, boxes, and butt-shoulder joints are contra-indicated [26]. After the preparation of the tooth is made, a final impression is made and a working die model is fabricated. The die is ditched, clearly defining the margin. It is positioned vertically in the die holder. Using a touch probe scanner, the CAD/CAM technology will scan the margins and preparation design to create a coping, either made from alumina or zirconia [27].

In the Procera AllCeram system, the coping material is composed of a densely sintered high-purity alumina (99.9%). It is important that the properties of the aluminum oxide coping and the AllCeram porcelain are harmonious to create the best crown. The coefficient of thermal expansion of aluminum oxide is 7x 10 (-6) nanometer/mL. Therefore, the AllCeram porcelain must be used to match the coefficient of thermal expansion to the aluminum core. The advantages of Procera crowns include excellent esthetics, increased strength as compared to older generations of ceramics, and advancement in technology [26]. These advantages have allowed clinicians and researchers to investigate the use of Procera crowns in posterior regions.

Procera crowns may also be made with a zirconium oxide coping. In dentistry, zirconium dioxide based materials are stabilized with yttrium-stabilized tetragonal zirconia polycrystals (Y-TZP) [22]. Zirconium oxide ceramics have high strength, excellent mechanical properties, and are biocompatible. “In contrast to conventional feldspathic ceramic, the matrix pressure on the tetragonal particles of zirconium oxide is reduced by tensile stresses that induce a transformation of the tetragonal to a monoclinic phase" [28]. There is also a 3-5% volumetric increase of the zirconium, resulting in compressive stresses that counteract the external tensile stresses. This may allow for transformation toughening, a prevention of propagation of cracks. Due to its manufacturing process, the intaglio surface of both AllCeram and AllZirkon Procera copings have a unique micro-roughness which aids in the micro-mechanical interlocking of bonding and luting agents [28].

Procera AllZirkon crowns have proved not only their fine esthetics but they are also strong retainers. Procera AllCeram and AllZirkon prove to be esthetic, strong, and durable, permitting the use of Procera on posterior teeth. In conjunction, molars tend to have a small height to base ratio and commonly have inadequate retention and resistance form when prepared for a crown. Thus, secondary factors such as grooves often need to be incorporated. However, to minimize stress to the prosthesis, the use of sharp line angles, boxes, grooves and 'butt' type shoulders is contra-indicated [26]. Due to the high demand for esthetics but the fundamental need for strong preparation principles, it is necessary to test the effect of grooves on Procera crowns.

The purpose of this study is to test the placement of grooves on crown preparations that will be restored by Procera crowns by putting the crown through retentive and resistive forces. Relentlessly applying the principles of tooth preparation is necessary to create a strong substructure for restorations. Currently, there have been studies performed on the placement of grooves of tooth preparations being restored by PFM and cast metal crowns. However, the effectiveness of groove placement on posterior teeth being restored by Procera crowns is unknown. In addition, the scanning mechanism of the CAD/CAM technology may or may not be able to detect intricacies such as grooves in tooth preparations precisely. This study will examine the load to dislodgement at vertical and horizontal forces of Procera crowns with groove placement in tooth preparation before and after scanning the die model.

2 PURPOSE

The purpose of this study is to investigate the effect of placing grooves on a tooth preparation for a full coverage zirconia Procera restoration on the load to dislodgement at a 40 degree force of the restoration. Dislodgement will be tested by varying the tooth preparations as follows:

1. Preparation with no grooves
2. Preparation with grooves placed before scanning the die model
3. Preparation with grooves placed after scanning the die model

3 HYPOTHESIS

NULL –

There is no significant difference in dislodgement forces of Procera crowns with the absence of grooves on the preparation, presence of grooves placed before scanning and the presence of grooves placed after scanning of the preparation.

RESEARCH –

There is a significant difference in dislodgement forces of Procera crowns with the absence of grooves on the preparation, presence of grooves placed before scanning and the presence of grooves placed after scanning of the preparation.

4 MATERIALS AND METHODS

Stainless steel dies:

Three standardized stainless steel dies (4 Hour Day Machine Shop, Baltimore, MD) simulated a mandibular molar crown preparation without retention and resistance form. The dimensions of the dies were 3 mm in height and 10 mm in base, 1.5 mm rounded chamfer finish line with a 30 degree total occlusal convergence (Fig. 1). The dies were centered in a cube of autopolymerizing acrylic resin (Ortho-Jet Clear, Lang Dental Manufacturing Co. Inc., Wheeling, IL) in the dimensions of 20x10x10 mm. Two 40° notches were made in the acrylic cube on the mesial and distal dimensions using a protractor. The block was replicated using lab putty(Lab-Putty Hard, Coltene Whaledent Inc., Cuyahoga Falls, OH) from an initial wax-up(Fig. 4,5,6).

Groove placement and experimental design:

The first die was used to resemble a preparation with no grooves and served as the control group. The second die resembled a preparation with two grooves placed on the mid-mesial and mid-distal walls. The third die resembled a preparation with two grooves also placed on the mid-mesial and mid-distal walls; however, the grooves were placed after the dies are scanned. (Fig. 2) Grooves were placed by 4 Hour Day Machine Shop. The grooves had a depth of 1.0 mm, width of 1.0 mm and a height of 2.0 mm.

Fabrication of zirconia copings:

The stainless steel dies were scanned via the Procera® Piccolo scanner (Prosthodontics Laboratory, Baltimore College of Dental Surgery, University of Maryland, Baltimore, MD). The information was sent electronically to Procera manufacturing facility (Mahwah, New Jersey) to fabricate the zirconia copings for each of the dies (the number of copings used was determined by the power analysis based on a pilot study with 5 specimens each) (Fig. 3). The internal fit of the zirconia copings was checked using a test-fit silicone paste (Fit Checker, GC). The marginal fit was inspected using 10X magnification (SMZ 2T Nikon, Japan) and illumination (Lumina, Chiu Technical Corporation, New York). Zirconia abutments that were not acceptable were discarded and not used in the experiment. A 1.5 mm uniform thickness of compatible porcelain (Nobelrondo Zirconia) was applied to the zirconia copings using a porcelain-firing oven (Pro Press 100, Whip Mix Corporation, Louisville, Kentucky). A putty (Lab-Putty Hard, Coltene Whaledent Inc., Cuyahoga Falls, OH) index fabricated from an initial wax up on the stainless steel dies will be used to apply porcelain in a uniform thickness.

Cementation of the crowns:

Zinc phosphate cement (HY-Bond™, Shofu Dental Corporation, San Marcos, CA) was used to cement the zirconia crowns to the stainless steel dies. The cement was mixed in proportions according to the manufacturer’s instructions and loaded into the intaglio surface of the zirconia abutment. The crowns were seated onto the respective dies using constant seating force generated by the use of finger pressure. Excess cement was removed using a plastic scaler (Premier®, Plymouth Meeting, Philadelphia, PA). The specimens are left undisturbed for 24 hours at room temperature prior to dislodgement testing procedures.

Testing of dislodgement:

A universal load-testing machine (Satec™ Universal Materials Testing, Instron®, Norwood, MA) was used to measure the peak load to dislodgement required to remove the crowns from the dies. The specimens were attached to the machine using a holder(Fig. 7). A compressive force applied obliquely at a speed of 0.05 inches per minute was used (Potts 1980).

To apply the force, a metal rod (10mm x 2mm) was applied to the stainless steel dies where the notch is on the coping at a 40 degree angle(Fig. 8). Because the grooves were placed on the mesial and distal surfaces, the forced was applied from the buccal direction. Therefore, a notch was placed 2 mm deep on the mid-buccal wall at the margin of the crown in porcelain. An atypical style of testing for dislodgement was used. If a force is placed on the occlusal surface of an all-ceramic crown, the porcelain is likely to fracture before actual dislodgement can occur. Therefore, dislodgement was tested via a "push" movement in a combined vertical and horizontal direction(Fig. 9).

Forces were applied until dislodgement of the crown occurs. The forces required to dislodge the crown were recorded in Newtons (N).

Once the crowns were separated from the respective dies, the stainless steel dies were placed in an ultrasonic bath of distilled water at room temperature for 5 minutes, steam cleaned and air dried to allow for further cementation and testing procedures (Fig. 10).

Statistical analysis:

Data will be analyzed using the one-way ANOVA statistical test. Tukey's Honestly Significant Differences (HSD) Test was used to determine the significant difference found among the groups. A p value of $p \leq 0.0001$ was considered significant. With an n=50 in each group, $p \leq 0.0001$, an effect size of 0.20, power = 0.81. Despite these results, it was decided to use n=30 due to time and expenses.

5 RESULTS

There was a significant difference among the three experimental conditions ($F = 213.69$, $p \leq 0.0001$). Procera crowns cemented on dies with grooves (two grooves, 1 mm in width and 1 mm in depth) prepared before scanning the die had a significantly higher load to dislodgement than all other groups (3850 ± 370 N). Procera crowns cemented on dies with grooves prepared after scanning exhibited the second highest load to dislodgement (2610 ± 250 N). The lowest value of load to dislodgement was found in Procera crowns with no grooves prepared on dies (control group) (2260 ± 300 N). Grooves after scanning (Tukeys HSD = 2.60) had a significantly higher load to dislodgement than the control group (Tukeys HSD = 2.26) (Table 1).

Examples of load to dislodgement recorded for each of the groups are represented in Figures 11,12,13. These figures demonstrate the amount of load needed in Newtons to dislodge the Procera crown at a 40° angle on a tensile force. The highest point of each line in the graph represents the peak load needed to extricate the Procera crown off of the stainless steel die.

The cement tended to remain on the coping for the control group after testing (Fig 10). For the other groups with grooves on the dies, cement was distributed between the coping and the dies with cement remaining in the grooved areas.

6 DISCUSSION

This study demonstrated that in a laboratory simulation of a clinically compromised complete-coverage tooth preparation, placing grooves increased load to dislodgement of Procera zirconia crowns thus rejecting the null hypothesis. The literature supports this concept in that the addition of secondary factors such as grooves increases the resistance and retention form of a preparation as it applies to PFM and cast metal crowns.

The control group without any grooves needed the least load to dislodgement because there was no retention or resistance form to the preparation. Secondary factors were also not present to aid in possible retention of the crown. Grooves placed in the die after scanning was also not the most effective method in retaining the crown because the additional surface area created was mainly contacted by cement, as opposed to the zirconia crown itself. Therefore, there was no interlocking between the coping and the die. Grooves placed before scanning not only increased the surface area of the crown preparation [11] but also helped provide a closer contact between the coping and die.

The primary variables affecting the retention of prosthetic crowns include the convergence of the preparation walls, the area of retentive surface and the length of axial walls [12]. The control group of the study did not possess any of the qualities required for proper retention because it is common to find mandibular molar preparations lacking in retention and resistance form. Several authors describe the addition of grooves to increase retention form of a preparation [4,13,15,14] and although none of these studies report on all-ceramic crowns, this study is in agreement that the addition of secondary factors does increase the load required for dislodgement on zirconia crowns, as well as PFM and metal crowns.

Teteruck and Mumford investigated the degree of adaptation with different cast metal 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, there was positive contact area observed between the die and the crown at the occlusal region and never in the cervical region. The reason for this lack of intimate contact between tooth and cast metal is unknown [29].

In this study, there was a lack of intimate contact between the die and crown in the region of the groove due to the difference in depth and width of the groove created in the die and its counterpart in the crown as determined using a negative putty imprint of the crown and a micrometer. This probably occurred because of the method of fabricating the coping has limitations in detecting the grooves due to the size of the touch probe scanner. Regardless of this lack of intimate contact, the addition of the grooves greatly increased the load to dislodgement of the Procera crowns.

By testing specimens where two interproximal grooves were placed after the scanning for fabrication of a zirconia coping, the concept of cement keys was evaluated. Worley found that there was no significant improvement in retention between grooved and non-grooved teeth when the cast crown did not account for the groove. This is not in accordance with other published studies. Tylman stated that cement keys between opposing grooves in dentin and in the casting will increase resistance to vertical displacement since greater reliance is placed on the bulk strength of the cement. He tested this by using inlays with a single horizontal groove around the circumference and the strength doubled as a result of the grooves [30]. Chan also found that the addition of opposing grooves in the tooth and cast gold crown nearly doubled the amount of retention as opposed to no grooves at all. It was concluded that cement keys provide a clinically useful increase in retention to highly tapered crowns [20]. Zinc phosphate cement achieves retention by mechanical interlocking with irregularities in the tooth and casting and has no chemical adhesion to tooth structure.

Witwer and von Fraunhofer found that increased retention is associated with a greater proportion of the cement residue retained within the cast crown than on the prepared tooth. Results from this study conclude that increased retention was associated with a division of cement retained on the die and in the zirconia crown as found in both groups containing grooves; however there was greater cement residue in the zirconia crown for the control group, where the least amount of load to dislodgement was required. Reasons for these differences may be due to (1) use of stainless steel dies as opposed to natural extracted teeth due to the increased roughness and wetness of a natural tooth (2) use of zirconia crowns instead of cast crowns due to the accurate technique in fabricating the cast crowns as opposed to a CAD/CAM design (3) difference in the dimensions and finish line of the preparations and (4) type and depth of grooves used in the study (0.5mm circumferential vs. 1.0mm interproximal) [13].

This study differed from others in that the load to dislodgement was tested at a 40° angle. In mastication or parafunctional movements, forces are applied to the tooth at an angle. The 40° angle helped simulate this concept. Most other studies used a direct vertical pull test [3, 4, 14] to test retention or in an oblique direction to test resistance [16]. This study tested a combination of retention and resistance in a more clinically acceptable manner.

Adjunctive future studies may include testing different types of scanning mechanisms for CAD/CAM copings such as the optical scanner, comparing grooves on Procera crowns versus PFM, cast metal, or lithium disilicate crowns, or completing a pull test as opposed to a push test.

7 CONCLUSION

Grooves placed before scanning of dies provided the most improvement load to dislodgement of Procera zirconia crowns in a clinically simulated model.

8 TABLES

Experimental Groups	Mean (N)	SD	F
Grooves placed before scan	3850a	370	213.69
Grooves placed after scan	2610b	250	
No grooves placed	2260c	300	

*groups with different letters denote significant differences, $p \leq 0.0001$

Table 1. Load to Dislodgement Values (Newtons) N = 30

9 FIGURES

Figure 1. Stainless Steel Die

Figure 2. Stainless Steel Die with Grooves

Figure 3. Zirconia Copings

Figure 4. Fabrication of Acrylic Holding Cube

Figure 5. Verification of 40° Angle

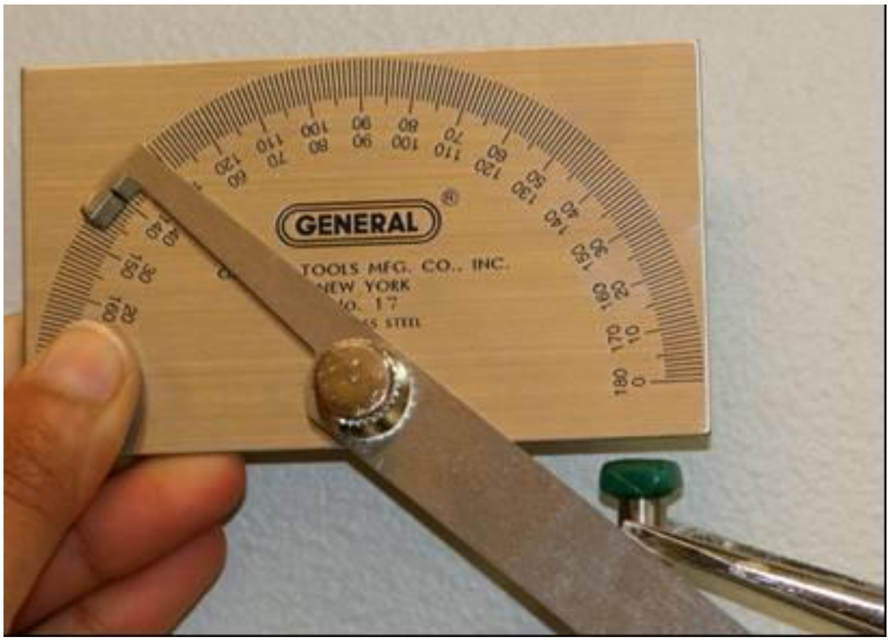


Figure 6. Replication of Acrylic Block

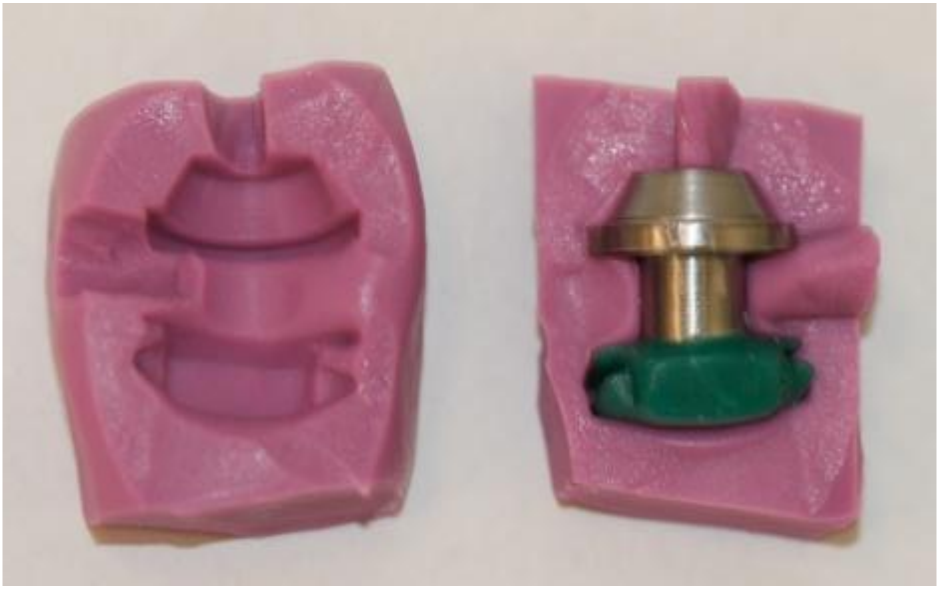


Figure 7. Stainless Steel Die With Acrylic Block and Holding Jig at 40° Angle

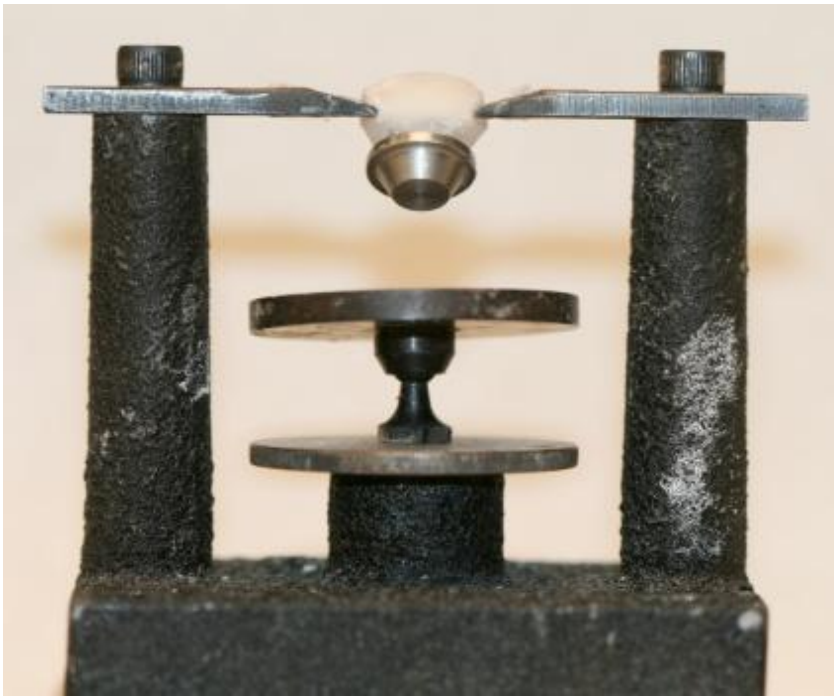


Figure 8. Metal Rod

Figure 9. Holding Jig and Metal Rod on Universal Load Testing Machine

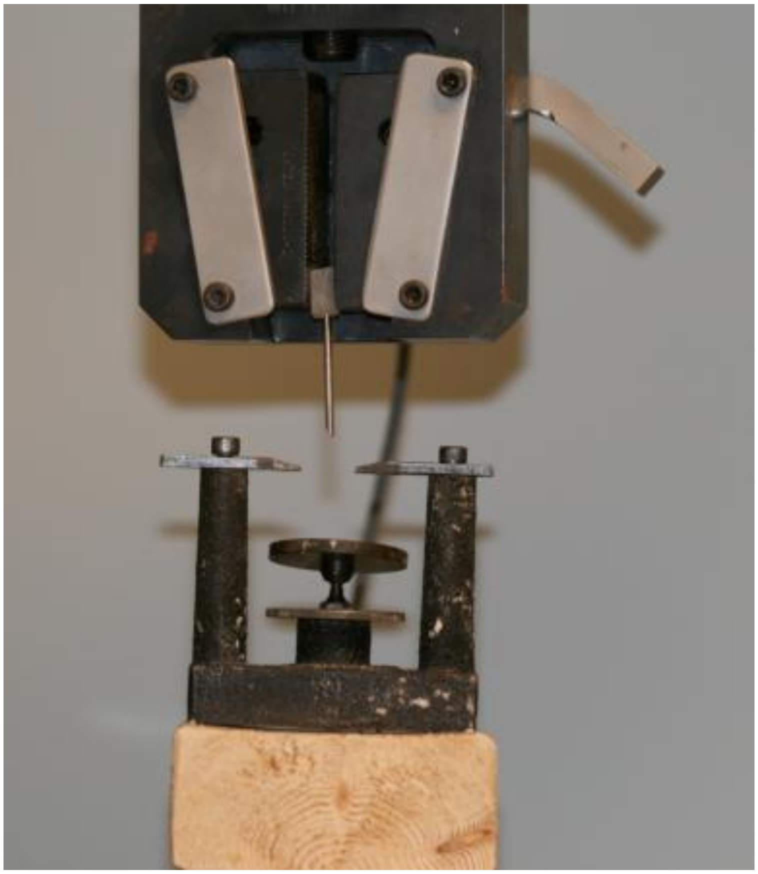


Figure 10. Cement Distribution after Dislodgement

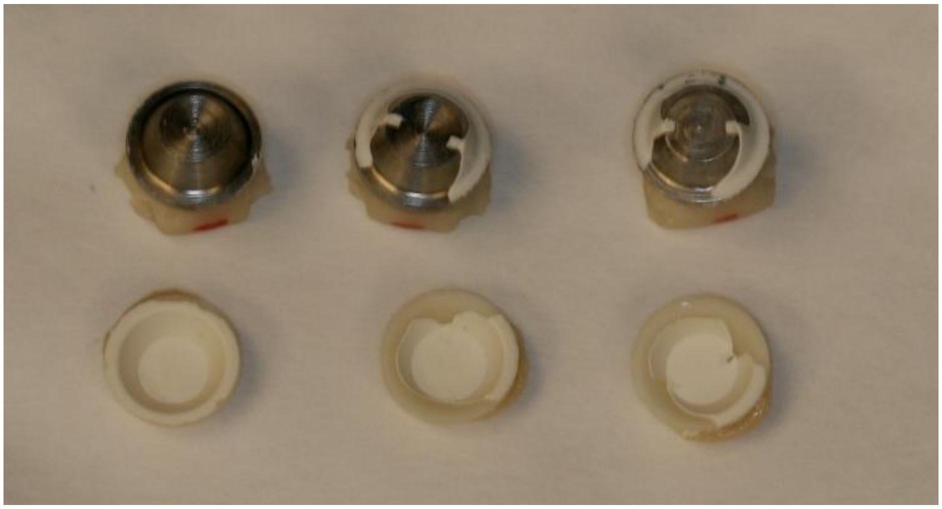


Figure 11. Sample Test of the Load to Dislodgement of a Procera Crown When Grooves are Prepared Before Scanning

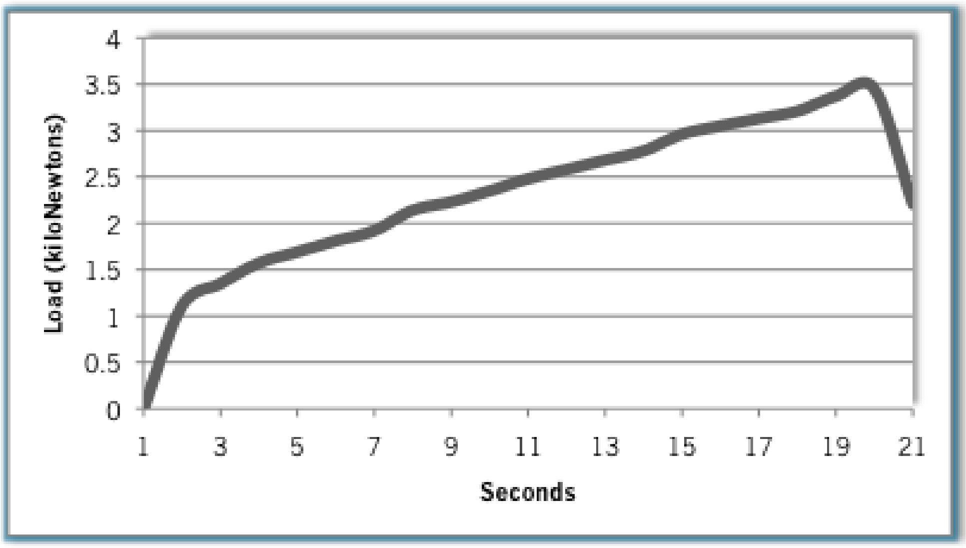


Figure 12. Sample Test of the Load to Dislodgement of a Procera Crown When Grooves are Prepared After Scanning

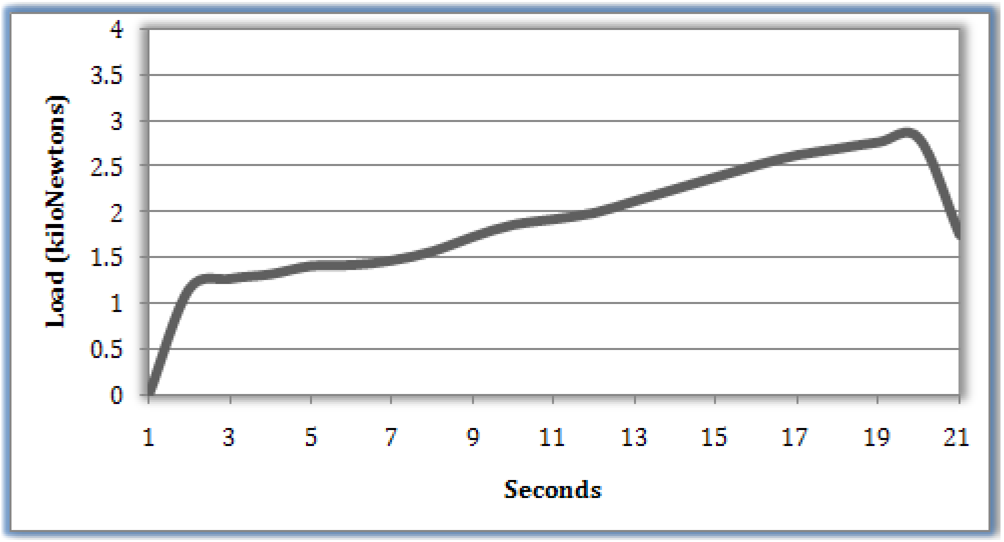
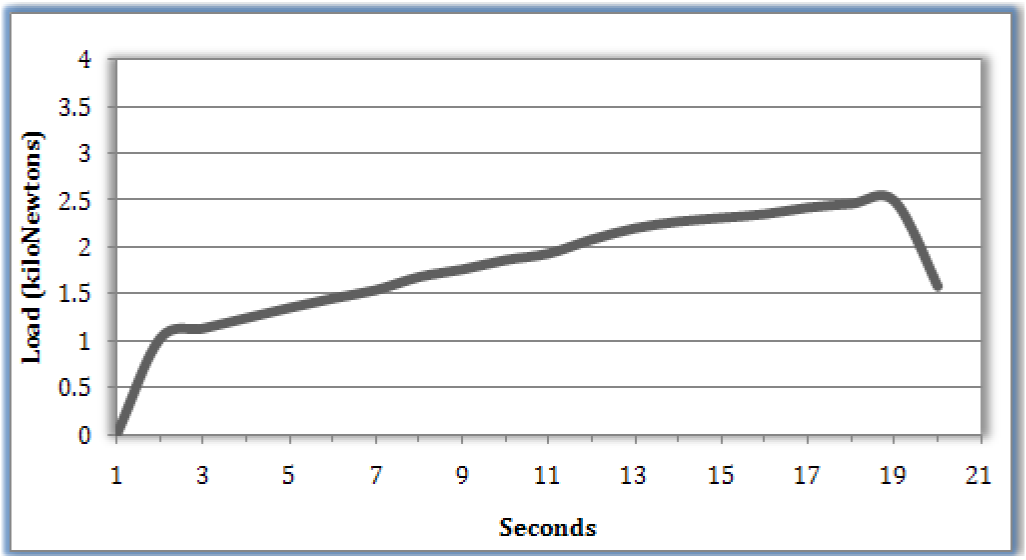


Figure 13. Sample Test of the Load to Dislodgement of a Procera crown When No Grooves are Prepared



10 APPENDIX 1: POWER ANALYSIS

Factor Name	Number of levels	Cases per level	Effect size f	Power
Groove Condition	Levels = 2	50	0.28	0.81

Within cell SD = 1.00, Variance = 1.00

Cases per cell = 50, Total N of cases =100

Alpha (2-tailed) = 0.05

Power computations: Non-central F

11 APPENDIX 2: RESULTS OF STATISTICAL ANALYSIS

One-Way ANOVA

Descriptives

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
Grooves placed after scanning	30	2.6050	.24944	.04554	2.5119	2.6981
Grooves placed before scanning	30	3.8487	.37403	.08829	3.7090	3.9663
No grooves	30	2.2583	.30402	.05551	2.1448	2.3719
Total	90	2.9040	.75329	.07940	2.7462	3.0618

Descriptives

	Minimum	Maximum
Grooves placed after scanning	2.00	2.99
Grooves placed before scanning	3.22	4.70
No grooves	1.75	2.80
Total	1.75	4.70

Test of Homogeneity of Variance

Levene Statistic	df1	df2	Sig.
2.404	2	87	.096

ANOVA

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	41.960	2	20.980	213.685	.000
Within Groups	8.42	87	.098		
Total	50.502	89			

Post Hoc Tests

Homogeneous Subsets

Tukey HSD

Groups	N	Subset for alpha = 0.05		
		1	2	3
No grooves	30	2.2583		
Grooves placed after scanning	30		2.6050	
Grooves placed before scanning	30			3.8487
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

12 APPENDIX 3: RAW DATA

GROUP	NO GROOVES	GROOVES PLACED BEFORE SCAN	GROOVES PLACED AFTER SCAN
PEAK LOAD TO DISLODGEMENT (KiloNewtons)	2.12	4.05	2.67
	2.8	3.31	2.49
	2.68	3.45	2.43
	2.66	3.28	2.4
	2.34	4.7	2.23
	1.89	3.56	2.71
	2.21	4.45	2.5
	2.18	3.9	2.36
	2.79	3.54	2.1
	2.51	3.65	2
	2.67	4.21	2.89
	2.05	4.36	2.56
	1.99	3.84	2.79
	1.87	3.73	2.45
	2.23	3.69	2.65
	2.15	4	2.53
	2.45	3.42	2.71
	2.05	4.11	2.85
	2.11	3.34	2.77
	1.92	4.01	2.78
	2.18	3.67	2.74
	2.43	4.32	2.93
	1.88	4.28	2.91
	2.16	4.06	2.57
	2.28	3.22	2.69
	1.75	3.99	2.3
	1.86	3.87	2.92
	2.66	3.88	2.5
	2.57	3.92	2.73
	2.31	3.65	2.99
MEAN (KiloNewtons)	2.258333	3.848867	2.605

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