The comparison of tensile strength among different surfaces of implant custom abutments

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Sae-Eun Schlottke, D.D.S.

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Heather Joan Conrad, D.M.D.
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DEDICATION

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ABSTRACT

Purpose

This in-vitro study was designed from a clinical case and investigated how mechanical and chemical changes on implant abutment surfaces would result in different tensile strengths between computer-aided design/computer-aided manufactured lithium disilicate crowns and implant abutments.

Material & Methods

A clinical case master cast of a maxillary right central incisor single implant restoration was utilized to fabricate five different abutment types: titanium smooth surface (Ts), titanium with retentive grooves (Tr), titanium with titanium nitride coating without grooves (Gs), titanium with titanium nitride coating with retentive feature (Gr), and zirconia(Z). A total of 50 lithium disilicate crowns were fabricated and equally divided into five groups. The maximum tensile strength of each combination was measured using a universal testing machine until the interface failed.

Results

The rank of mean retention value was found from highest to lowest, titanium with titanium nitride coating with grooves (Gr), titanium with titanium nitride coating without grooves (Gs), titanium with retentive grooves (Tr), titanium without retentive grooves (Ts), and zirconia (Z). One-way ANOVA analysis indicated the retention value of the Gr has statistically significant difference compared to all other groups ($p < 0.05$). Gs and Gr both significantly improved retention compared to Z group (p value < 0.05). No statistically significant differences were found between other pairs of groups in terms of retentiveness.

Conclusion

The retentive grooves or titanium nitride coating on titanium alloy abutments alone did not significantly increase retention, but when they were used together, there was substantial improvement in retention. Titanium with titanium nitride coating in conjunction with retentive grooves can significantly improve the surface retention compared to a zirconia abutment. This data can be used by clinicians in clinical decision-making when additional retention is desired in the esthetically challenged regions such as the anterior maxilla.

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CHAPTER 1: INTRODUCTION

Successful implant restorative therapy depends not only on the osseointegrated implant but also the integrity of the prosthesis that delivers function to the oral cavity.[1] When a patient is missing a tooth, a tooth-supported fixed dental prosthesis (FDP) or an implant-supported single crown can be fabricated to restore esthetics and function. The latter has shown favorable success rates compared to the FDP option.[2]

Cement-retained implant-supported prostheses, when compared to their screw-retained counterparts, are more advantageous in regards to esthetics and occlusion. This is because the screw access channel is not incorporated into the crown. It allows the crown to have a continuous coverage and structural integrity without the need to add a restorative material to fill the screw access channel.[3] Cement-retained restorations are, however, more challenging to retrieve in case of abutment screw loosening or fracture, abutment fractures, or necessary surgical re-intervention.[4]

To overcome the difficulty of the retrieval process, temporary cements, such as zinc-oxide eugenol and non-eugenol zinc-oxide, have been suggested for cementation of implant restorations.[5] This, in turn, may result in more frequent crown decementation that can lead to more chairside time for the restorative dentist.[4] In order to minimize this complication, several studies have recommended the use of glass-ionomer, zinc phosphate, and resin composite luting agents. These cements have shown to enhance the cement failure loads of the prostheses on titanium abutments in comparison to provisional luting agents.[6-8]

Various custom abutment types and designs are available to clinicians for implant fixed restorations. With high esthetic demands in the maxillary anterior region, gold-shaded titanium nitride-coated abutments and zirconia abutments have been popular materials of choice.[9,10]

The aim of this study was to investigate the effects of different abutment materials and surface designs on the tensile bond strength of resin-based temporary cement with a lithium disilicate crown. The results from this study will allow clinicians to select the most optimal material and design when considering esthetics and function for each clinical case.

CHAPTER 2: LITERATURE REVIEW

1. FIXED DENTAL PROSTHESIS VS. IMPLANT-SUPPORTED FIXED PROSTHESES

As dental implants become a more established treatment option, increasing number of patients with partial edentulism are opting for implant-supported fixed prostheses (ISFP) as an alternative to traditional fixed dental prostheses (FDP).[2] Studies show comparable survival rates between FDP and ISFP in restoring a missing tooth.[11]

The most frequent complications for FDP are biological complications, such as loss of abutment tooth vitality and caries, followed by technical complications, such as loss of retention caused by cement fracture.[12] With ISFD, technical complications are more common than biological complications. Technical complications for ISFD include abutment screw loosening and fracture of veneering material, while biological complications include peri-mucositis and peri-implantitis. The incidence of technical complications of ISFD is significantly higher than that of FDP.[13]

2. SCREW-RETAINED VS. CEMENT-RETAINED RESTORATIONS

There are two different techniques used to provide restorations for implant-supported prostheses: screw-retained and cement-retained prostheses. The advantages and disadvantages of each method have been discussed in the literature in terms of esthetics, occlusion, porcelain fracture resistance, passive fit, and other considerations.[4,14-16]

Screw-retained prostheses provide a great advantage over cement-retained restorations in terms of their retrievability. Screw access channel provides ease of retrieval of the implant superstructure in the event of abutment screw loosening, and surgical reintervention.[17] In order to provide the same benefits, implant provisional cements were suggested for ease of cement-retained crown retrieval.[4,5,18]

Inadequate retention under function and water solubility were encountered when non-eugenol zinc oxide or zinc oxide eugenol cements were used. Mehl[19] studied retrievability of cement-retained crowns with five cement types and concluded that zinc phosphate and glass ionomer cement are suitable for "semi-permanent cementation". Additionally, the pull-out test by Sheets[20] with various cements including resin-based provisional cement provides data ranking the mean value of load required to break the bond between the abutment and the casting. Resin-based provisional cement commonly used for implant restoration had an average value of 131.6N (+/-31.8) in this study.

Another study showed that resin adhesive provisional cement had the strongest retentive values, while non-eugenol zinc-oxide exhibited the lowest retentive values. The author suggested that non-eugenol zinc-oxide could be the most appropriate cement when retrievability and removal of the provisionally cemented superstructure is anticipated.[21]

Despite the main advantage of retrievability for screw-retained restorations, cement-retained restorations have several distinctive advantages. An example of this can be seen in the maxillary anterior region. Although prosthetically-driven implant surgery has been heavily emphasized for the optimal function and longevity of implant superstructure, the challenges of implant placement with ideal angulation still remains in the anterior maxilla.[22] The presence of anatomical undercuts in the apical portion of the anterior maxilla restricts the ideal positioning of the implant, which may affect the screw access channel by making it appear on the facial surface instead of lingual to the incisal edge.[23] To manage concerns regarding the visibility of the screw access channel, cement-retained implant crowns on custom abutments have been recommended in the esthetic zone, making the restoration more esthetically pleasing. In addition, patients may prefer cement-retained implant restoration in the mandibular arch as the color difference of the composite resin restoration in the screw access channel compared to the surrounding porcelain may be unacceptable esthetically.

Occlusal stability is another topic of interest in comparison between screw-retained and cement-retained implant restorations. When the screw access channel is sealed with composite resin, ideal occlusion may be compromised particularly if the opposing restoration has porcelain occlusion. Ekfeldt[24] documented that the contacts established on the composite resin in the screw access channel opposing a porcelain restoration is not stable when it comes to long term prognosis due to wear. Considering this, cement-retained implant restorations may provide more predictable occlusal stability.

Torrado[25] concluded that, regardless of where the screw access opening is on the occlusal surface, screw-retained restorations demonstrated significantly lower porcelain fracture resistance compared to cement-retained restorations. Hebel[3] pointed out that esthetics and occlusion should not be arbitrarily sacrificed in return for retrievability of implant-supported restorations since the survival rate of implants has significantly improved, and proper handling of cement-retained restorations may provide retrievability.

In regards to passive fit, Taylor[26] stated that cement-retained implant superstructures have the potential of being completely passive compared to screw-retained restorations; however, pure passivity of a restoration is extremely rare due to errors accumulating in each step of prosthesis fabrication.

A non-passively fitting prosthesis can negatively influence the effect of load transfer to the prosthesis-implant-bone system. This can lead to additional bone loss and the migration of microorganisms in the gap between the implant and the abutment. Guichet[27] studied the relationship of marginal discrepancy and passive fit of screw-retained and cement-retained implant fixed dental prosthesis designs. He concluded that cement-retained FDP had significantly less stress concentrations around the implants related to its passive fit. This was explained by noting that the cement layer compensated for the errors accumulated during prosthesis fabrication. It is also suggested that the intervening cement layer acts as a shock absorber and enhances the transfer of load from prosthesis through the implant to the bone.[28] Additionally, prosthetic complications such as loosening or fracture of abutment screws and implant fracture can occur due to non-passively fitting framework.

Although cement-retained restorations have many benefits, a critical concern and drawback is the possibility of residual cement left in the sulcus after cementation.[29] Residual excess cement may cause bone loss around implants and potentially lead to implant loss.[30] The signs of peri-implantitis caused by excess cement include swelling, bleeding on probing, deep pocket depth, and radiographic loss of peri-implant bone. Some of these signs of inflammation may not appear for years after the restoration has been cemented. In order to reduce residual excess cement on the implant surface, it is recommended to use individually designed abutments by the use of casting or computer-aided design/computer-aided manufacturing (CAD/CAM) technology, which brings the restoration margin closer to the free gingival margin and eases the excess cement removal process.[31]

Another way to reduce the possibility of leaving residual cement on the implant or abutment surface is to create a practice abutment or an abutment analog. It can be done by taking an impression of the abutment, which then can be poured with pattern resin material.[32] The restoration is filled with cement and placed onto the abutment analog. After excess cement is removed, the restoration is then seated onto the definitive abutment. Lastly, a screw access channel can be incorporated within the crown during the fabrication process. This allows for extraoral cementation of the crown on the abutment and for the excess cement to escape through the screw access channel when the restoration is cemented.[33] A disadvantage of this technique is that the screw access channel will need to be sealed with a restorative material which may be an esthetic concern and may increase the risk of porcelain fracture as seen in screw-retained implant restorations.[4]

3. Factors Contributing to Retention of Implant Restoration

The factors that affect the retention of restorations on implants are similar to those factors that affect the retention of restorations on natural teeth. Implant manufacturers machine their implant abutments with 6 degrees of taper, which is documented to be ideal.[34] Considering the fact that most clinicians prepare teeth with taper between 15 and 25 degrees, cement-retained restorations can have significantly improved retention compared to full cusp coverage restorations on natural teeth, assuming all other factors are constant.[35]

A rough axial wall surface improves the retention of the restoration, and can be produced by either a diamond bur or airborne particle abrasion.[36] Most studies involving air particle abrasion on titanium surfaces [37-39] use 50 μm aluminum oxide particles at a pressure of 2 bars for 10 seconds with a distance of 10 mm between the specimen and the sandblast gun tip. The sandblasted surface increases the retention, but the degree of increase depends on the type of cement.[1] Although more retention can be achieved with a roughened surface, it is not necessary to modify the surface if ideal taper and sufficient axial wall heights are present.[4]

Retention and resistance forms can be improved by modifying the abutment surface area and axial wall height.[40] Compared to stock abutments, the surface area and axial wall height of implant custom abutments can be created ideally.[41] A stock abutment used in a molar site may have a compromised retention form due to the discrepancy in size between the implant and the partially edentulous space. With the emergence of computer aided design of custom abutments, it became possible to increase the abutment surface area to resemble the natural tooth morphology.[7]

Definitive cements are becoming more popular for implant-supported restorations since the survival rate of dental implants is increasing and the prosthetic component connection is becoming more stable, although complications and concerns still remain with loosening and/or fracture of abutment screws.[42] These cements should only be used when retrieval of prosthesis and surgical intervention for peri-implantitis is not anticipated.[5]

4. Implant Abutment Material

4.1. Titanium Abutment

Commercially pure titanium and titanium alloys have been used in dentistry for more than two decades because of their superior biocompatibility when compared to other metals used for dental prostheses.[43] The most commonly used titanium alloy used is titanium with 6% aluminum and 4% vanadium (Ti-6Al-4V), which can be designed and machined using CAD/CAM technology.[44] Although its metallic color showing through soft tissue can compromise esthetics, its desirable mechanical and physical properties compared to ceramic abutments have made it a popular material of choice.[45]

4.2. Titanium Abutment with Anodized Surface

Titanium oxide is a thin film of approximately 20 nm that allows light to reflect off the underlying titanium alloy which produces a gray hue.[46,47] This thin layer causes light interference and can give off different wavelengths of the visible light spectrum. The desired colors such as yellow and pink can mask the color of titanium alloy and be useful for maxillary anterior restorations.[48]

The anodization process involves titanium alloy being connected to a positive electric probe, which is then submerged into an electrolytic solution. When a voltage is applied to the electrolyte, electrons are deposited onto the titanium by a self-limiting process.[49] The thickness of a post-anodized TiO_2 layer is close to that of the visible light wavelength and can produce optical interference patterns.[50]

This anodized surface does not alter the surface chemistry but maintains the surface biocompatibility.[51] This inexpensive, simple, rapid technique can improve esthetics of the restoration and soft tissue for an implant restoration.[52]

4.3. TITANIUM ABUTMENT WITH TITANIUM NITRIDE COATING

Titanium Nitride (TiN) is an extremely hard ceramic that can be prepared by direct reaction of titanium or titanium hydrogen powder with nitrogen at 1200 ºC. It has general properties such as great hardness (2000 kg/mm2), high decomposition temperature (2949 ºC), and superconductivity.[53] Additionally, TiN coating enhances other materials such as titanium alloy with its excellent biological properties, hardness, resistance to corrosion, and decorative yellowish color.[9,54] This gold-hue color was adapted to the implant abutment industry to obtain esthetically pleasing results under the soft tissue in the esthetic zone.[10]

There are multiple techniques to achieve a TiN coating on titanium alloy ($TiAl_6V_4$), which include nitrogen ion implantation, physical vapor deposition, and plasma ion nitriding.[55] Galetz[56] concluded in his study that physical vapor deposition (PVD) of TiN, which is the most common technique to prepare TiN coating on titanium alloy, is shown to increase roughness due to multiple small pits and pinholes found on the surface of TiN as it shows in the image of dark field light microscopy (Figure 1). These defects are typically generated during the growth of the coating in the PVD process.

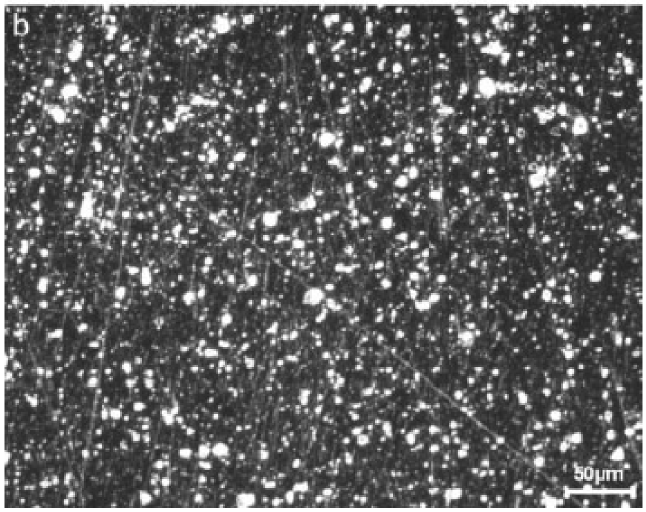

Figure 1. TiN coating under the dark field light microscopy

4.4. ZIRCONIA ABUTMENT

Zirconia is a crystalline dioxide of zirconium, which can be organized in three different patterns: monoclinic, cubic, and tetragonal. It has mechanical properties similar to those of stainless steel with a compression resistance of about 2000 MPa.[57] Mixing ZrO_2 with other metallic oxides such as MgO, CaO, or Y_2O_3 can result in great molecular stability. Yttrium-stabilized zirconia, also known as tetragonal zirconia polycrystal, is currently the most studied combination. It has better mechanical properties than other combinations although it is more difficult to sinter.[58]

One of the great properties of zirconia is transformation toughening, which happens when a force on the zirconia surface induces volumetric changes in the crystalline structure.

During this process, the transformation from tetragonal to monoclinic seals the expansion of cracks.[59] There are some concerns, however, regarding zirconia material. Exposure to moisture for an extended period of time, such as in an oral environment, can cause changes in the physical properties of zirconia. This phenomenon where zirconia is subject to aqueous and low temperature degradation is called “zirconia aging”. Surface grinding can also introduce microcracks on the surface, thus reducing toughness.[60]

Zirconia abutments are available as prefabricated and customized abutments. The custom abutment is favored over a prefabricated abutment because of the ability to control emergence profile and to locate the margin for residual cement removal.[61] Although zirconia abutments have earlier reports of high success rates, particularly in the anterior region where lower forces are applied, [62-64] some concerns remain regarding the long-term performance of zirconia abutments. These concerns include the fracture tendency of zirconia abutments with the narrow diameter implants[65] and fritting between the zirconia abutment and titanium implant that may lead to misfit of the component, damage to implant surface, promotion of micromotion, and mechanical failure.[66]

In order to maximize the esthetic results, all-ceramic restorations are preferred as a material of choice for zirconia abutments.[67] The surface of zirconia abutments can be treated to improve bonding with all-ceramic restorations and provide better longevity of the restorations. Bonding of resin cement with zirconia is shown to reduce microleakage and increases retention.[68,69] Because zirconia is not etchable, additional surface treatment may be necessary to achieve stronger adhesion using resin cement.[70,71] Tzanakakis [72] summarized micromechanical and chemical bonding techniques available for zirconia surfaces as seen in Figure 2.

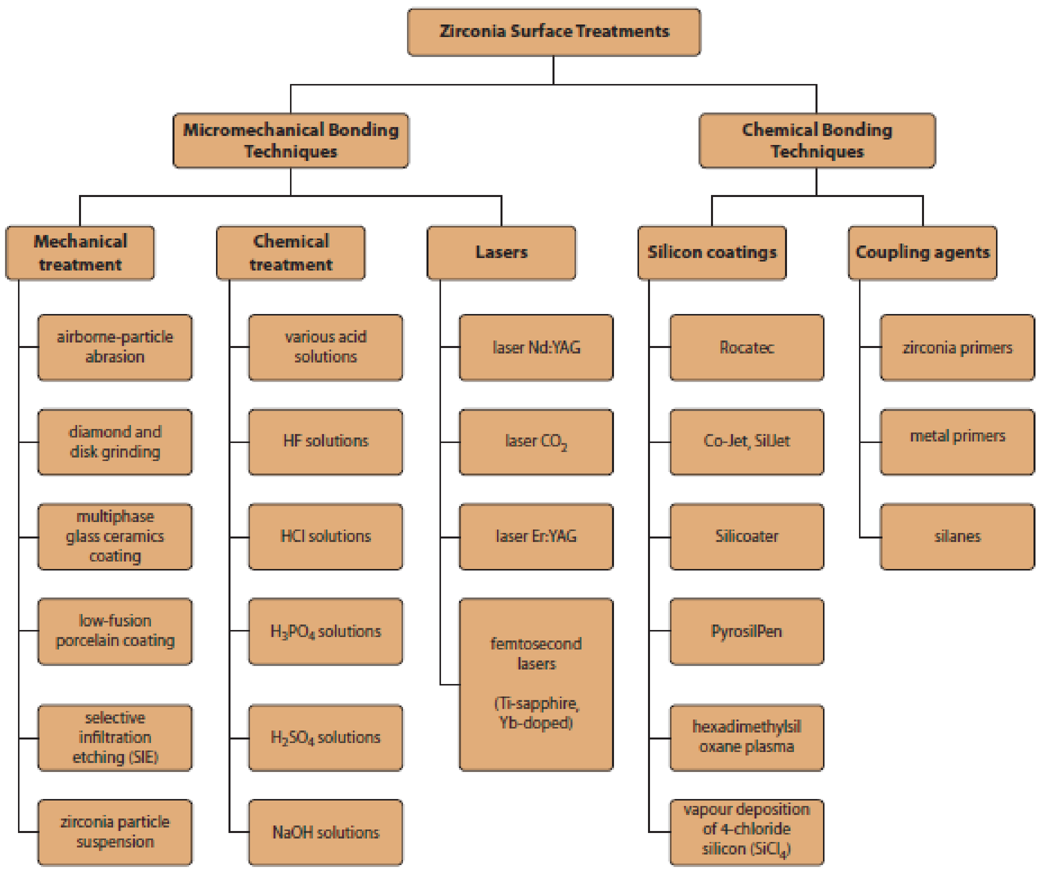

Figure 2. Summary of zirconia surface treatments

5. ALL-CERAMIC CROWN

Ceramic materials deliver excellent esthetics and function in the anterior and posterior regions of the oral cavity. The two most common ceramic materials are zirconia and lithium disilicate. Zirconia has greater mechanical strength, but less light translucency than lithium disilicate. Both materials have been reported to have complications of cracking, chipping, and fracturing veneer porcelain material.[73]

Lithium disilicate glass-ceramic was introduced into the market in 1998 as IPS Empress 2 (Ivoclar Vivadent), but due to its higher failure rate as a FDP framework, this material was discontinued.[74] The newer version of lithium disilicate, which is a pressable and machinable monolithic material, has been marketed since 2005 as IPS e.max. Through a different firing process, e.max was made with improvements to its translucency and flexural strength (360 Mpa) when compared to IPS Empress 2.[75] This material soon became popular among practitioners who desire a metal-free restoration with good strength and esthetics.[76]

A systematic review on lithium disilicate performance indicates that it shows excellent survival rates in the short- term, but the evidence for medium-term survival rates is limited. The study also indicates that the majority of failures occurred in the posterior region and that lithium disilicate FDPs are discouraged in this area.[77] The physical properties of lithium disilicate are listed in the table 1.[78]

Table 1. Physical characteristics and properties of lithium disilicate

Physical properties	LS2 complete cystallized state
Biaxial strength	360 ± 60Mpa
Vickers hardness	5,800 ± 200 Mpa
Modulus of elasticity	95 ± 5 GPa
Density	2.5 ± 0.1 g/cm^3

SPECIFIC AIM

To measure the tensile strength between an implant custom abutment of different surface materials and designs of lithium disilicate glass ceramic crowns when the crowns are cemented with resin-based temporary cement.

STATEMENT OF THE PROBLEM

Various types of materials and designs of an implant abutment is available to assist esthetics and function of implant therapy in the maxillary anterior region. There were no studies found that compared these various types of custom abutments in terms of their retentiveness when resin-based temporary implant cement is used.

NULL HYPOTHESIS (H0)

The difference in surface material and the presence of retentive features on the implant custom abutment of this specific manufacturer will not influence the retentiveness of a lithium disilicate all-ceramic crown when cemented with resin-based implant temporary cement.

ALTERNATE HYPOTHESIS (H1)

The difference in surface material and the presence of retentive feature on the implant custom abutment of this specific manufacturer will influence the retentiveness of a lithium disilicate all-ceramic crown when cemented with resin-based implant temporary cement.

CHAPTER 3: METHOD AND MATERIALS

The design of a custom abutment (ATLANTIS abutment; Dentsply implants) made for a 4.0mm by 13mm maxillary right central incisor implant (OsseoSpeed TX; DENTSPLY implants) from a clinical case (Figure 3) was digitally duplicated with five different types of abutments by the manufacturer: titanium smooth surface (Ts), titanium with retentive feature (Tr), titanium gold-hue without retentive feature (Gs), titanium gold-hue with retentive feature (Gr), and zirconia (Z) (Figure 4).

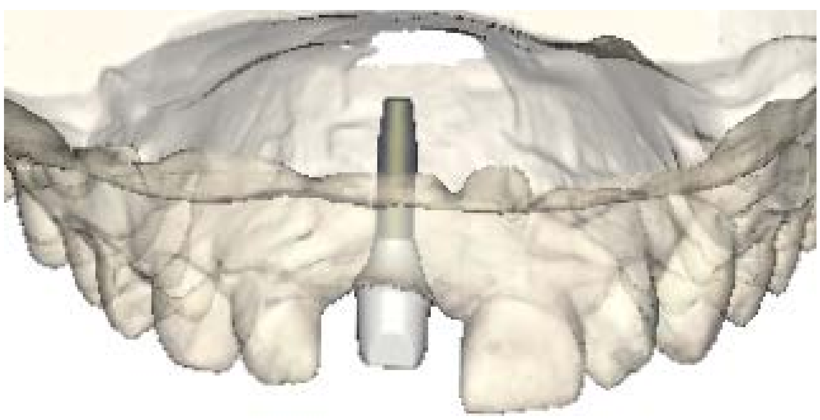

Figure 3. Custom abutment fabrication

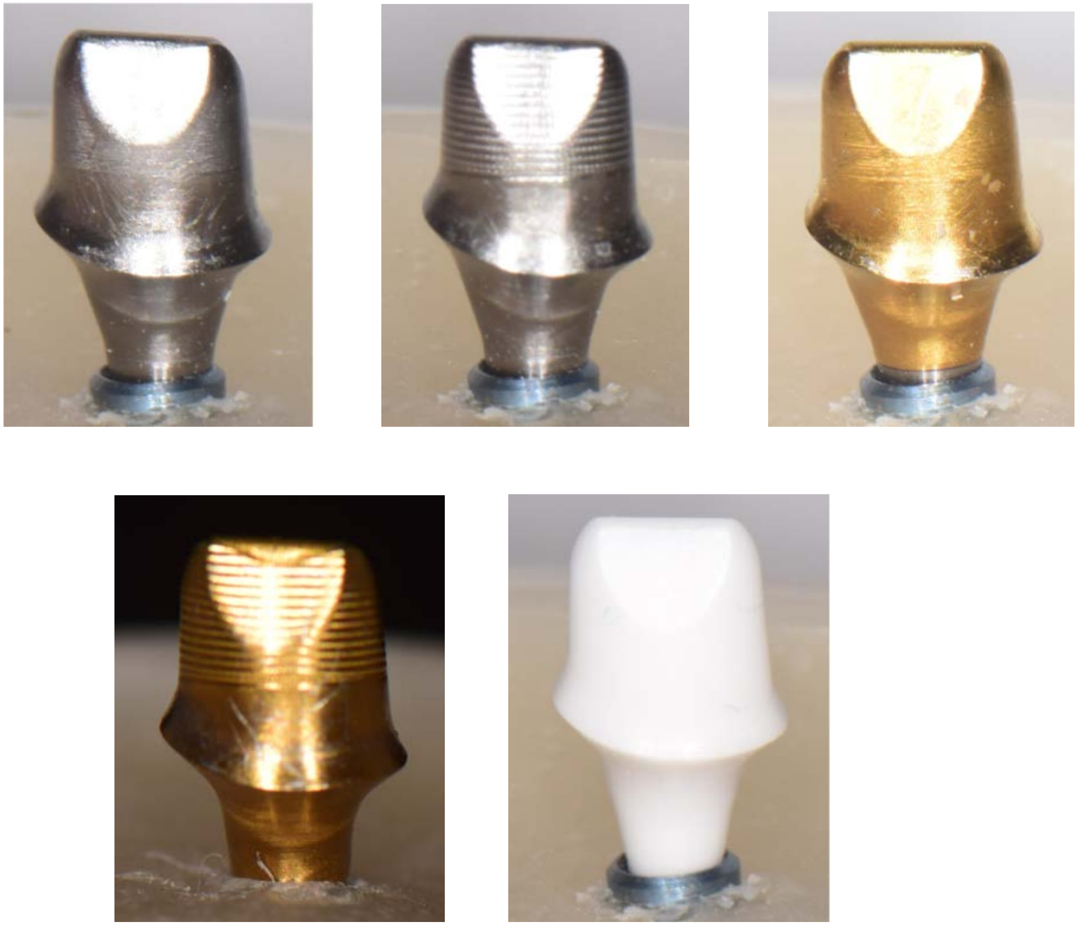

Figure 4. Different abutment types: a) Titanium with no groove b) Titanium with retentive grooves c) Titanium gold hue d) Titanium gold hue with retentive grooves e) Zirconia

Total convergence taper of the abutment is 6 degrees and the height from the most apical facial margin to the top of the abutment is 4mm. A wax-up model was created on a zirconia abutment with pod-like extensions on the mesial and distal sides for the pull-out test machine to hold on to (Figure 5,6).

Figure 5. Maxillary right central incisor implant crown wax-up

Figure 6. Maxillary right central incisor implant crown modified wax-Up

The zirconia abutment and the wax model were both scanned with an optical scanner (NobelProcera; Nobel Biocare, Zurich, Switzerland) (Figure 7,8). The default die space of the scanner is 70 μm. A total of 50 CAD/CAM lithium disilicate crowns (IPS e.max, Ivocalar Vivadant, Somerset, NJ) were milled. The shape of each crown and its fit on the master abutment of each group were examined at the stage of blue-colored intermediated crystalline phase. Each crown went through the final firing cycle according to the manufacturer's recommendation on the duration and temperature of the cycle (Table 2) (Figure 9).

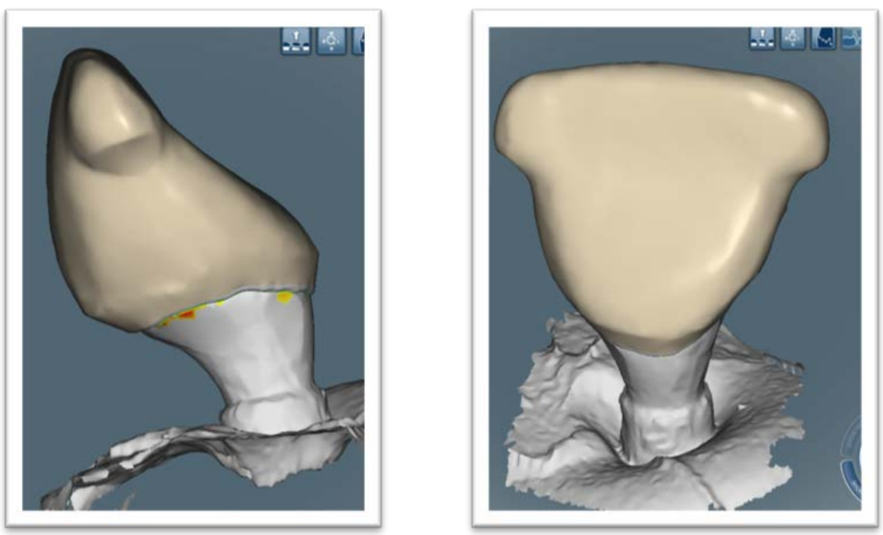

Figure 7. Scanning wax-up model

Figure 8. NobelProcera Scanner **Figure 9.** Vita Vacuumat 40

The crowns were divided equally into five groups (n =10). With 20 Ncm torque value, each master abutment was connected on to the implant analog that was embedded in the clear orthodontic acrylic resin bath (Caulk Orthodontic Resin; Dentsply, Milford, DE). An inch-long Teflon tape was cut and placed into the screw access channel to protect the screw hex. A resin-based implant temporary cement (Premier Implant Cement; Premier, Plymouth Meeting, PA) was dispensed on to a mixing pad between two lines that were 7 mm apart (Figure 10). The distance was determined to standardize the quantity of the cement. The cement was then loaded into the internal surface of each, and the excess cement was removed with a micro brush. By monitoring the instant feedback from the axial load vs. the time graph shown on the MTS 858 Mini Bionix monitor, consistent finger pressure of 10 Ncm was achieved until complete setting was reached. According to the manufacturer’s instruction, the working time of the temporary cement is 2 minutes, and the setting time is 4 minutes from dispensing. (Figure 11)

Figure 10. Premier Implant Cement

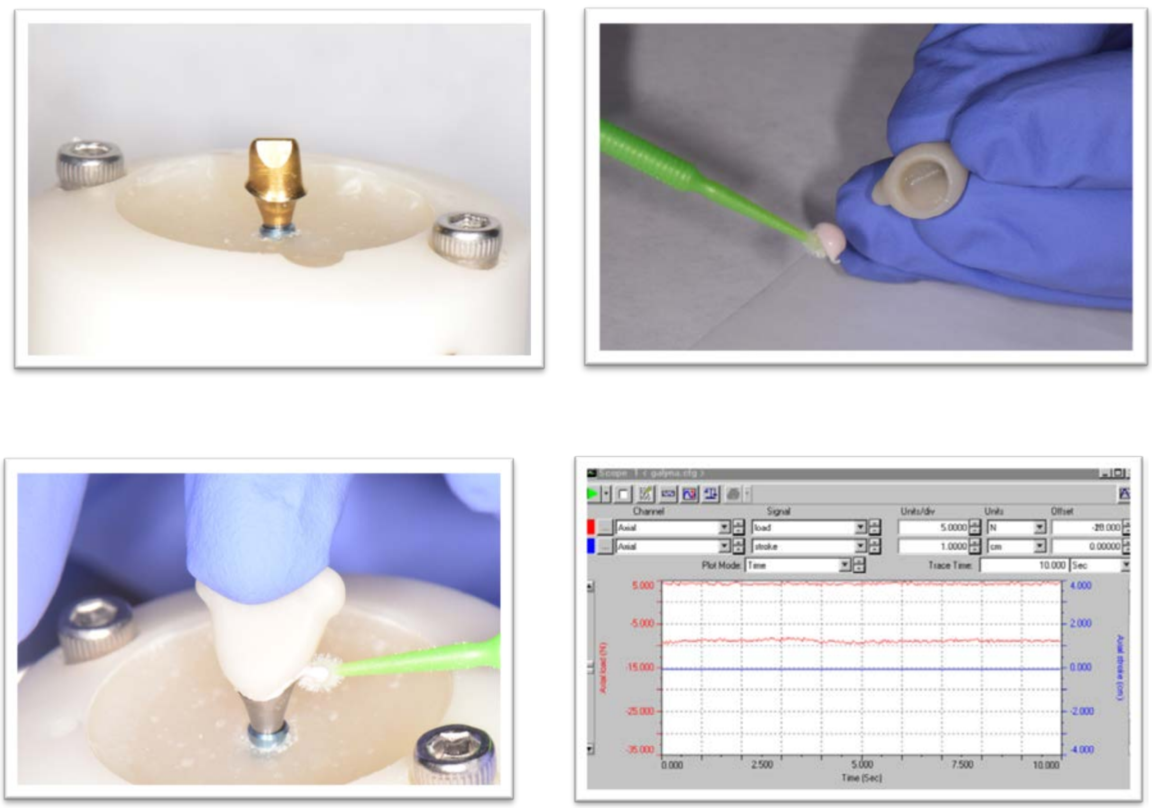

Figure 11. Cementation procedures a) Abutment attached to the analog b) Cement application c) Excess cement removal d) Cementation pressure

The pull-out apparatus was assembled and the crosshead speed was set at 5 mm/min in a universal testing machine (MTS 858 Mini Bionix II) (Figure 12). The axial load and axial stroke were recorded against time, and the data of the maximum axial load was collected. Once the maximum axial load was reached, the crown was separated from the abutment. The abutment was then cleaned with 0.12% chlorhexidine (Peridex Oral Rinse; 3M, St. Paul, MN) and a piece of 2 x 2 clinical gauze (Avant Gauze®; Medline, Mundelein, IL). The specimens were dried and visually inspected to ensure complete removal of the luting agent. The process was repeated with all five groups.

Figure 12. Testing machine a) Universal testing machine, MTS 858 Mini Bionix II b) Pull-up test apparatus c) Close-up attachment

Table 2. Firing parameters crystallization

	Stand-by Temperature (ºC)	Closing Time (min)	Heating Rate [ºC/min]	Firing Temperature (ºC)	Holding Time (min)	Heating Rate [ºC/min]
P300						
P500	403	6:00	90	820	0:10	30
P700						

	Firing Temperature (ºC)	Holding Time (min)	Vacuum1 11(ºC) 12(ºC)	Vacuum2 21(ºC) 22(ºC)	Long-term cooling [°C]	Cooling rate [°C/min]
P300						
P500	840	7:00	550 770	770 850	700	20
P700						

For the statistical analysis, a spreadsheet in an XLS file was created with the types and designs of custom abutments with the maximum cement failure loads. For group comparison, one-way analysis of variance (ANOVA) was used to analyze the data. An overall p-value was generated to find out if there were at least two groups significantly different from each other ($p < 0.001$). To find out which groups were different, pairwise comparisons were performed with Tukey-Kramer method for multiple comparison adjustment. A p-value of < 0.05 was considered significant.

CHAPTER 4: RESULTS

The null hypothesis stated that the difference in surface material and the presence of retentive features on the implant custom abutment of this specific manufacturer will not influence the retentiveness of a lithium disilicate all-ceramic crown when cemented with resin-based implant temporary cement. The primary analysis involved five test groups with a total of 50 all-ceramic crowns from which cement failure loads were collected. The mean, median, minimum and maximum tensile forces required to pull the all-ceramic crowns from different types and designs of custom abutments are presented in Table 3 and Figure 13.

Each master abutment had a similar interface failure mode that involved adhesive failure followed by cohesive failure. All of the resin-based provisional cement was found on the intaglio surface of the first all-ceramic crown tested in each group, but in the second test and beyond, the cement was found on both the abutment surfaces and the intaglio surfaces of the all-ceramic crowns.

Overall p-value of one-way ANOVA statistic was calculated ($p < 0.001$) and concluded that there were at least two groups that are statistically significant. Pairwise comparisons were performed with Tukey-Kramer method for multiple comparison adjustment.

Table 3. Mean and median value (N) of each test group

Test Groups	Category			
	N	Median	Mean (SD)	(Min, Max)
Ts	10	94.58	98.13 (13.91)	(83.09, 118.5)
Tr	10	96.94	98.36 (6.13)	(92.25, 109.9)
Gs	10	102.5	103.2 (5.86)	(96.61, 113.6)
Gr	10	123.9	124.4 (17.88)	(92.49, 152.7)
Z	10	80.58	84.77 (13.80)	(69.03, 109.6)

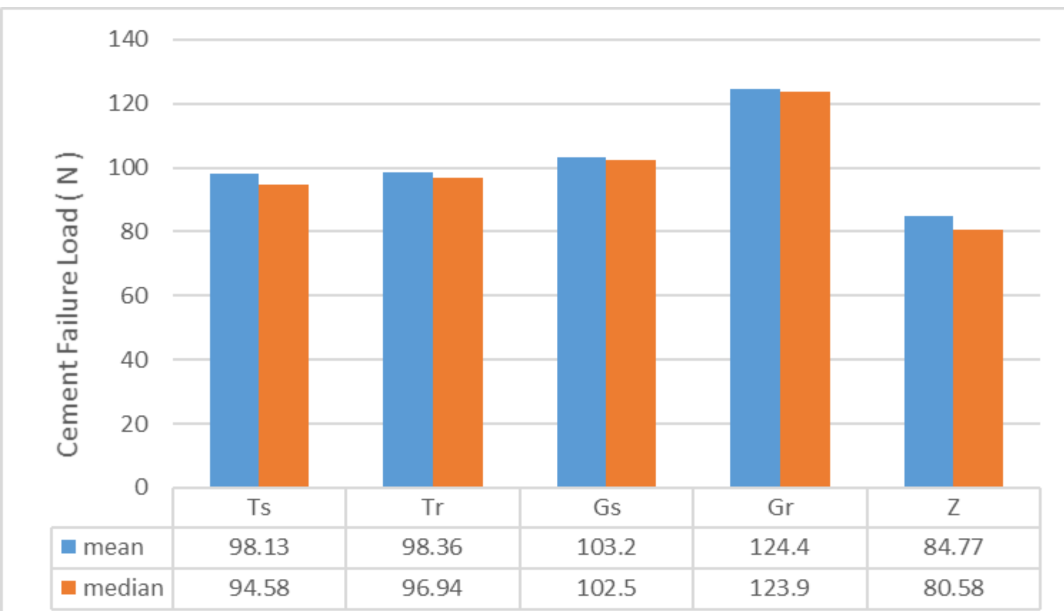

Figure 13. Mean and median value (N) of each test group

The abutment of titanium gold-hue with retentive grooves (Gr) showed the highest cement failure load followed by titanium gold-hue smooth surface (Gs), titanium with retentive grooves (Tr), titanium with smooth surface (Ts), and zirconia (Z). There was a statistically significant increase in retentiveness from Gr compared to all other groups. (Table 4)

Table 4. Statistical comparison among test groups

GROUP 1	GROUP 2	Estimate	Standard Error	Adjusted P-value
Gs	**Ts**	5.043	5.5694	0.8933
Gs	**Tr**	4.81	5.5694	0.9086
Gs	**Gr**	-21.267	5.5694	0.0036 *
Gs	**Z**	18.4	5.5694	0.0153 *
Ts	**T**	-0.233	5.5694	1
Ts	**Gr**	-26.31	5.5694	0.0002 *
Ts	**Z**	13.357	5.5694	0.1345
Tr	**Gr**	-26.077	5.5694	0.0002 *
Tr	**Z**	13.59	5.5694	0.1234
Gr	**Z**	39.667	5.5694	<.0001 *

The retentive grooves on a titanium abutment did not increase the tensile strength at a statistically signicant level. Conversely, retentive grooves on titanium gold-hue abutment did considerably increase the te nsile strength ($p < 0.0036$). The titanium nitride coating on titanium abutment showed a slight elevation in the mean value of tensile strength, but did not have a substantial effect when compared to the control group. The zirconia abutment showed the lowest value of cement failure load among all test groups but demonstrated statistical significance only with Gr group.

CHAPTER 5: DISCUSSION

The data from this study partially support the acceptance of the null hypothesis; that there is no difference among Ts, Tr, and Gs groups. With Gr group in comparison to the rest of the test groups (Ts, Tr, Gs, Z), however, the null hypothesis was rejected. ($p < 0.0002$, 0.0002, 0.0036, <.0001). In addition, Z group showed statistically significant difference compared to Gs group. ($p < 0.0153$)

Cement-retained implant restorations are commonly used in restorative dentistry especially when it is necessary to hide a screw access channel. In the anterior maxilla, the implant placement may not be ideal for screw-retained implant restorations, so a cement-retained restoration may be an excellent alternative to provide the best possible esthetic results.

One of the most common technical complications with implant restorations are abutment screw-loosening,[79-81] When that complication arises, either the screw needs to be retightened or replaced with a new one. Another complication that may occur throughout the life of the implant restoration is peri-implantitis.[12,82] When there is an active infection around the implant, additional treatment is indicated.[83] During the treatment, the restoration may have to be detached from the implant for better prognosis of the treatment. Other complications include fracture of abutment screws or abutment hex, veneering layer fracture of restoration that requires laboratory repair or fabrication of a new restoration, and implant loss.[84]

The screw channel is easily accessible with a screw-retained implant restoration but can be more challenging to accurately locate in a cement-retained restoration. Provisional cement has been proposed for cementing implant restorations to simplify access to the abutment screw. With the benefit of retrievability of provisional cement, there comes a disadvantage of frequent decementation and increased chairside time for the restorative dentist. Akca[85] concluded in his study that provisional cements have low uniaxial resistance forces when used with implant-supported crowns, and it may necessitate frequent recementation of implant-supported crowns. The application of permanent cement or selecting an abutment that provides improved retention may be necessary for abutments with decreased axial wall surfaces due to smaller implant sizes. Dramatically corrected angle of the implant at the abutment level may also lead to significant loss of abutment wall surface area, which compromises retention of the restoration.[86]

This investigation was to compare the retentiveness of different abutment surface designs and materials on which lithium disilicate restorations were cemented with resin-based implant provisional cement.

No studies were found that reported on the tensile strength of a cement-retained all-ceramic restoration when cemented with implant provisional cement on either titanium or zirconia abutments. The data from the five test groups resulted in slightly lower mean value of tensile strength than that of Sheets'[20] study, which used the same type of cement but a cast metal coping as a restoration: the mean uniaxial forces noted in the study was 131.6N (+/-31.8). Considering the smooth intaglio surface of the monolithic lithium disilicate all-ceramic crown, it is reasonable to conclude that the data of this study is comparable with that of Sheets'.

The failure mode observed in this study suggests that the finished surfaces of the abutments are relatively smooth. The first pull-out test resulted in adhesive failure with most of the cement being inside the lithium disilicate crowns. Successive tests showed cohesive failures with the cement being on both the abutments and the intaglio surfaces of the crowns. This implies that the finished surface was removed with the cement layer during the first pull-out test. This surface may have been created by the manufacturer to give polished surface characteristics.

The retentive grooves on this particular manufacturer's titanium abutment may increase the surface area between the cement layer and the abutment, and also provide small undercuts for mechanical retention. The data did not show statistically significant increase of retention from this feature.

The thin coating of titanium nitride on a solid titanium grade 5 alloy (Ti-6Al-4V) provides warm gold-shaded color. This aids to overcome esthetic challenges in thin soft tissue when using an all-ceramic crown. Galetz[56] explained about PVD of titanium nitride on titanium alloy surfaces and how it creates small pits and pinholes during the growth of the PVD process. Although there is a slight increase in the mean value of maximum tensile strength, statistically significant improvement was not observed from this study.

When the retentive grooves and titanium nitride were combined, however, the uniaxial force of the cement layer break increased significantly. This can be explained by the synergistic effects of both retention grooves and the microscopic mechanical retention added from the PVD process.

It is worth noting that the Gr group had significantly better retention compared to Z group. Gold-hue titanium abutment and zirconia are the material of choice in the esthetic zone of the anterior maxilla when anticipating superior esthetic results. The results from this investigation suggest the use of Gr abutments in place of Z abutments when additional retention is indicated.

Limitations to the current study include small sample size and lack of simulating oral environment. Some in vitro studies stored cemented restorations in 100% humidity at 37°C for 24 hours, or other studies use artificial saliva and stored them at room temperature for 24 hours before a pull-out test was performed.[21,85,87] This study did not include this extra step to mimic the oral environment, and it could have affected the data accuracy in terms of numerical value. The relative retentiveness, however, of the data is still valid because all the test groups were tested under the same condition.

Another source of error could be introduced from non-standardized manufacturer's calibration. Because this study heavily relied on the accuracy of virtual technology in fabricating abutments and crowns, if there were inaccuracies in duplicating abutments with different types and designs, or in milling lithium disilicate crowns with multiple machines, it could have possibly caused errors in this study.

The future study is needed to reevaluate the synergistic effects of titanium nitride coating and mechanical grooves on titanium abutments. The surface treatment to increase retention on zirconia abutments can be investigated to provide additional data for clinical decision-making. In order to add more clinically relevant information, the specimen could undergo a certain number of cycles in a chewing machine, or artificial mouth, before a pull-out test is executed.

CHAPTER 6: SUMMARY AND CONCLUSION

This study was done to determine whether different surface materials and designs of implant custom abutments affected the retentiveness of all-ceramic crowns when cemented with a resin-based provisional cement. The null hypothesis was partially rejected. Based on the limitations of this study, the following conclusions may be drawn:

1. The retentive grooves in this specific manufacturer's custom abutment do not significantly affect retention on a titanium alloy abutment (Ti-6Al-4V).
2. The retentive grooves in this specific manufacturer's custom abutment increase retention if used on a titanium-nitride-coated titanium abutment.
3. Titanium nitride coating on titanium alloy abutment does not significantly increase retention.
4. When titanium nitride coating and the retentive grooves are used together, there is a synergistic effect that increases retention of lithium disilicate crowns.
5. Zirconia abutment showed the lowest mean value of tensile strength although the difference was only statistically significant with Gs and Gr.
6. When esthetics is a priority in the maxillary anterior region, a titanium abutment with titanium nitride coating (Gs) or titanium nitride coating with retentive grooves (Gr) can be used to improve retention of lithium disilicate restorations.

REFERENCES

1. Cano-Batalla J, Soliva-Garriga J, Campillo-Funollet M, Munoz-Viveros CA, Giner-Tarrida L. Influence of abutment height and surface roughness on in vitro retention of three luting agents. Int J Oral Maxillofac Implants 2012;27:36-41.

2. Muddugangadhar BC, Amarnath GS, Sonika R, Chheda PS, Garg A. Meta-analysis of failure and survival rate of implant-supported single crowns, fixed partial denture, and implant tooth-supported prostheses. J Int Oral Health 2015;7:11-17.

3. Hebel KS, Gajjar RC. Cement-retained versus screw-retained implant restorations: Achieving optimal occlusion and esthetics in implant dentistry. J Prosthet Dent 1997;77:28-35.

4. Michalakis KX, Hirayama H, Garefis PD. Cement-retained versus screw-retained implant restorations: A critical review. Int J Oral Maxillofac Implants 2003;18:719-728.

5. Breeding LC, Dixon DL, Bogacki MT, Tietge JD. Use of luting agents with an implant system: Part I. J Prosthet Dent 1992;68:737-741.

6. Kent DK, Koka S, Froeschle ML. Retention of cemented implant-supported restorations. J Prosthodont 1997;6:193-196.

7. Covey DA, Kent DK, St Germain HA,Jr, Koka S. Effects of abutment size and luting cement type on the uniaxial retention force of implant-supported crowns. J Prosthet Dent 2000;83:344-348.

8. Squier RS, Agar JR, Duncan JP, Taylor TD. Retentiveness of dental cements used with metallic implant components. Int J Oral Maxillofac Implants 2001;16:793-798.

9. Mezger PR, Creugers NH. Titanium nitride coatings in clinical dentistry. J Dent 1992;20:342-344.

10. Watkin A, Kerstein RB. Improving darkened anterior peri-implant tissue color with zirconia custom implant abutments. Compend Contin Educ Dent 2008;29:238-40, 242.

11. Pjetursson BE, Tan K, Lang NP, Bragger U, Egger M, Zwahlen M. A systematic review of the survival and complication rates of fixed partial dentures (FPDs) after an observation period of at least 5 years. Clin Oral Implants Res 2004;15:667-676.

12. Bragger U, Aeschlimann S, Burgin W, Hammerle CH, Lang NP. Biological and technical complications and failures with fixed partial dentures (FPD) on implants and teeth after four to five years of function. Clin Oral Implants Res 2001;12:26-34.

13. Bragger U, Karoussis I, Persson R, Pjetursson B, Salvi G, Lang N. Technical and biological complications/failures with single crowns and fixed partial dentures on implants: A 10-year prospective cohort study. Clin Oral Implants Res 2005;16:326-334.

14. Johansson LA, Ekfeldt A. Implant-supported fixed partial prostheses: A retrospective study. Int J Prosthodont 2003;16:172-176.

15. Karl M, Graef F, Taylor TD, Heckmann SM. In vitro effect of load cycling on metal-ceramic cement- and screw-retained implant restorations. J Prosthet Dent 2007;97:137-140.

16. Taylor TD, Agar JR. Twenty years of progress in implant prosthodontics. J Prosthet Dent 2002;88:89-95.

17. Chiche GJ, Pinault A. Considerations for fabrication of implant-supported posterior restorations. Int J Prosthodont c;4:37-44.

18. Ramp MH, Dixon DL, Ramp LC, Breeding LC, Barber LL. Tensile bond strengths of provisional luting agents used with an implant system. J Prosthet Dent 1999;81:510-514.

19. Mehl C, Harder S, Wolfart M, Kern M, Wolfart S. Retrievability of implant-retained crowns following cementation. Clin Oral Implants Res 2008;19:1304-1311.

20. Sheets JL, Wilcox C, Wilwerding T. Cement selection for cement-retained crown technique with dental implants. J Prosthodont 2008;17:92-96.

21. Michalakis KX, Pissiotis AL, Hirayama H. Cement failure loads of 4 provisional luting agents used for the cementation of implant-supported fixed partial dentures. Int J Oral Maxillofac Implants 2000;15:545-549.

22. Garber DA, Belser UC. Restoration-driven implant placement with restoration-generated site development. Compend Contin Educ Dent 1995;16:796, 798-802, 804.

23. Chee WW, Torbati A, Albouy JP. Retrievable cemented implant restorations. J Prosthodont 1998;7:120-125.

24. Ekfeldt A, Oilo G. Occlusal contact wear of prosthodontic materials. an in vivo study. Acta Odontol Scand 1988;46:159-169.

25. Torrado E, Ercoli C, Al Mardini M, Graser GN, Tallents RH, Cordaro L. A comparison of the porcelain fracture resistance of screw-retained and cement-retained implant-supported metal-ceramic crowns. J Prosthet Dent 2004;91:532-537.

26. Taylor TD, Agar JR, Vogiatzi T. Implant prosthodontics: Current perspective and future directions. Int J Oral Maxillofac Implants 2000;15:66-75.

27. Guichet DL, Caputo AA, Choi H, Sorensen JA. Passivity of fit and marginal opening in screw- or cement-retained implant fixed partial denture designs. Int J Oral Maxillofac Implants 2000;15:239-246.

28. Bidez MW, Misch CE. Force transfer in implant dentistry: Basic concepts and principles. J Oral Implantol 1992;18:264-274.

29. Pauletto N, Lahiffe BJ, Walton JN. Complications associated with excess cement around crowns on osseointegrated implants: A clinical report. Int J Oral Maxillofac Implants 1999;14:865-868.

30. Wilson TG,Jr. The positive relationship between excess cement and peri-implant disease: A prospective clinical endoscopic study. J Periodontol 2009;80:1388-1392.

31. Santosa RE, Martin W, Morton D. Effects of a cementing technique in addition to luting agent on the uniaxial retention force of a single-tooth implant-supported restoration: An in vitro study. Int J Oral Maxillofac Implants 2010;25:1145-1152.

32. Dumbrigue HB, Abanomi AA, Cheng LL. Techniques to minimize excess luting agent in cement-retained implant restorations. J Prosthet Dent 2002;87:112-114.

33. Sharifi MN, Pang IC, Chai J. Alternative restorative techniques of the CeraOne single-tooth abutment: A technical note. Int J Oral Maxillofac Implants 1994;9:235-238.

34. Wilson AH,Jr, Chan DC. The relationship between preparation convergence and retention of extracoronal retainers. J Prosthodont 1994;3:74-78.

35. JORGENSEN KD. The relationship between retention and convergence angle in cemented veneer crowns. Acta Odontol Scand 1955;13:35-40.

36. Felton DA, Kanoy BE, White JT. The effect of surface roughness of crown preparations on retention of cemented castings. J Prosthet Dent 1987;58:292-296.

37. Ebert A, Hedderich J, Kern M. Retention of zirconia ceramic copings bonded to titanium abutments. Int J Oral Maxillofac Implants 2007;22:921-927.

38. Kim Y, Yamashita J, Shotwell JL, Chong KH, Wang HL. The comparison of provisional luting agents and abutment surface roughness on the retention of provisional implant-supported crowns. J Prosthet Dent 2006;95:450-455.

39. Reddy SV, Reddy MS, Reddy CR, Pithani P, R SK, Kulkarni G. The influence of implant abutment surface roughness and the type of cement on retention of implant supported crowns. J Clin Diagn Res 2015;9:ZC05-7.

40. Kaufman EG, Coelho AB, Colin L. Factors influencing the retention of cemented gold castings. J prosthet Dent 1961;9:49-54.

41. Reid PE, Burke TM. Customized implant abutments: Technical notes. Implant Dent 1994;3:243-246.

42. Laney WR, Jemt T, Harris D, Henry PJ, Krogh PH, Polizzi G, et al. Osseointegrated implants for single-tooth replacement: Progress report from a multicenter prospective study after 3 years. Int J Oral Maxillofac Implants 1994;9:49-54.

43. Anusvice K, Phillips RW, Shen C, Rawls HR. Phillips' science of dental materials. St. Louis, Mo: Elsevier/Saunders; 2003.

44. Sghaireen MG. Fracture resistance and mode of failure of ceramic versus titanium implant abutments and single implant-supported restorations. Clin Implant Dent Relat Res 2015;17:554-561.

45. Leutert CR, Stawarczyk B, Truninger TC, Hammerle CH, Sailer I. Bending moments and types of failure of zirconia and titanium abutments with internal implant-abutment connections: A laboratory study. Int J Oral Maxillofac Implants 2012;27:505-512.

46. Wang RR, Fenton A. Titanium for prosthodontic applications: A review of the literature. Quintessence Int 1996;27:401-408.

47. Nakajima H, Okabe T. Titanium in dentistry: Development and research in the U.S.A. Dent Mater J 1996;15:77-90.

48. Stavenga DG. Thin film and multilayer optics cause structural colors of many insects and birds. Materials Today 2014;1S:109-121.

49. Karim MA. Electro-optical displays. London: Taylor and Francis; 1992.

50. Kern P, Schwalier P, Michler J. Electrolytic deposition of titania films as interference coatings on biomedical implants: Microstructure, chemistry and nano-mechanical properties. Thin Solid Films 2006;494:279-286.

51. Jaeggi C, Kern P, Michler J, Zehnder T, Siegenthaler H. Anodic thin films of titanium used as masks for surface micro patterning of biomedical devices. Surf Coat Technol 2005;200:1931-1919.

52. Wadhwani CP, O'Brien R, Kattadiyil MT, Chung KH. Laboratory technique for coloring titanium abutments to improve esthetics. J Prosthet Dent 2016;115:409-411.

53. Toth LE. Transition metal carbides and nitrides. New York, USA: Academic Press; 1971.

54. Wisbey A, Gregson PJ, Tuke M. Application of PVD TiN coating to co-cr-mo based surgical implants. Biomaterials 1987;8:477-480.

55. Maurer AM, Brown SA, Payer JH, Merritt K, Kawalec JS. Reduction of fretting corrosion of ti-6Al-4V by various surface treatments. J Orthop Res 1993;11:865-873.

56. Galetz MC, Fleischmann EW, Konrad CH, Schuetz A, Glatzel U. Abrasion resistance of oxidized zirconium in comparison with CoCrMo and titanium nitride coatings for artificial knee joints. J Biomed Mater Res B Appl Biomater 2010;93:244-251.

57. Piconi C, Maccauro G. Zirconia as a ceramic biomaterial. Biomaterials 1999;20:1-25.

58. Gupta TK, Bechtold JH, Kuznickie RC, Cadoff LH, Rossing B. Stabilization of tetragonal phase in polycrystalline zirconia. Journal of Materials Science 1978;13:1464-1470.

59. Garvie RC, Nicholson PS. Structure and thermodynamically properties of partially stabilized zirconia in the CaO-ZrO2 system. Journal of American Ceramic Society 1972;55:152-157.

60. Swab JJ. Low temperature degradation of Y-TZP materials. Journal of Materials Science 1991;26:6706-6714.

61. Bidra AS, Rungruanganunt P. Clinical outcomes of implant abutments in the anterior region: A systematic review. J Esthet Restor Dent 2013;25:159-176.

62. Zembic A, Bosch A, Jung RE, Hammerle CH, Sailer I. Five-year results of a randomized controlled clinical trial comparing zirconia and titanium abutments supporting single-implant crowns in canine and posterior regions. Clin Oral Implants Res 2013;24:384-390.

63. Glauser R, Sailer I, Wohlwend A, Studer S, Schibli M, Scharer P. Experimental zirconia abutments for implant-supported single-tooth restorations in esthetically demanding regions: 4-year results of a prospective clinical study. Int J Prosthodont 2004;17:285-290.

64. Canullo L. Clinical outcome study of customized zirconia abutments for single-implant restorations. Int J Prosthodont 2007;20:489-493.

65. Shabanpour R, Mousavi N, Ghodsi S, Alikhasi M. Comparative evaluation of fracture resistance and mode of failure of zirconia and titanium abutments with different diameters. J Contemp Dent Pract 2015;16:613-618.

66. Stimmelmayr M, Edelhoff D, Guth JF, Erdelt K, Happe A, Beuer F. Wear at the titanium-titanium and the titanium-zirconia implant-abutment interface: A comparative in vitro study. Dent Mater 2012;28:1215-1220.

67. Ekfeldt A, Furst B, Carlsson GE. Zirconia abutments for single-tooth implant restorations: A retrospective and clinical follow-up study. Clin Oral Implants Res 2011;22:1308-1314.

68. Manicone PF, Rossi Iommetti P, Raffaelli L. An overview of zirconia ceramics: Basic properties and clinical applications. J Dent 2007;35:819-826.

69. Ozcan M, Nijhuis H, Valandro LF. Effect of various surface conditioning methods on the adhesion of dual-cure resin cement with MDP functional monomer to zirconia after thermal aging. Dent Mater J 2008;27:99-104.

70. Ernst CP, Aksoy E, Stender E, Willershausen B. Influence of different luting concepts on long term retentive strength of zirconia crowns. Am J Dent 2009;22:122-128.

71. Qeblawi DM, Munoz CA, Brewer JD, Monaco EA,Jr. The effect of zirconia surface treatment on flexural strength and shear bond strength to a resin cement. J Prosthet Dent 2010;103:210-220.

72. Tzanakakis EG, Tzoutzas IG, Koidis PT. Is there a potential for durable adhesion to zirconia restorations? A systematic review. J Prosthet Dent 2016;115:9-19.

73. Chu SJ. Current clinical strategies with lithium-disilicate restorations. Compend Contin Educ Dent 2012;33:64, 66-7.

74. Helvey G. Ceramics. Compend Contin Educ Dent 2010;31:309-311.

75. Conrad HJ, Seong WJ, Pesun IJ. Current ceramic materials and systems with clinical recommendations: A systematic review. J Prosthet Dent 2007;98:389-404.

76. Christensen GJ. The all-ceramic restoration dilemma: Where are we? J Am Dent Assoc 2011;142:668-671.

77. Pieger S, Salman A, Bidra AS. Clinical outcomes of lithium disilicate single crowns and partial fixed dental prostheses: A systematic review. J Prosthet Dent 2014;112:22-30.

78. Joda T, Burki A, Bethge S, Bragger U, Zysset P. Stiffness, strength, and failure modes of implant-supported monolithic lithium disilicate crowns: Influence of titanium and zirconia abutments. Int J Oral Maxillofac Implants 2015;30:1272-1279.

79. Jemt T, Laney WR, Harris D, Henry PJ, Krogh PH,Jr, Polizzi G, et al. Osseointegrated implants for single tooth replacement: A 1-year report from a multicenter prospective study. Int J Oral Maxillofac Implants 1991;6:29-36.

80. Henry PJ, Laney WR, Jemt T, Harris D, Krogh PH, Polizzi G, et al. Osseointegrated implants for single-tooth replacement: A prospective 5-year multicenter study. Int J Oral Maxillofac Implants 1996;11:450-455.

81. Ekfeldt A, Carlsson GE, Borjesson G. Clinical evaluation of single-tooth restorations supported by osseointegrated implants: A retrospective study. Int J Oral Maxillofac Implants 1994;9:179-183.

82. Behneke A, Behneke N, d'Hoedt B. The longitudinal clinical effectiveness of ITI solid-screw implants in partially edentulous patients: A 5-year follow-up report. Int J Oral Maxillofac Implants 2000;15:633-645.

83. Leonhardt A, Dahlen G, Renvert S. Five-year clinical, microbiological, and radiological outcome following treatment of peri-implantitis in man. J Periodontol 2003;74:1415-1422.

84. Lekholm U, Grondahl K, Jemt T. Outcome of oral implant treatment in partially edentulous jaws followed 20 years in clinical function. Clin Implant Dent Relat Res 2006;8:178-186.

85. Akca K, Iplikcioglu H, Cehreli MC. Comparison of uniaxial resistance forces of cements used with implant-supported crowns. Int J Oral Maxillofac Implants 2002;17:536-542.

86. Emms M, Tredwin CJ, Setchell DJ, Moles DR. The effects of abutment wall height, platform size, and screw access channel filling method on resistance to dislodgement of cement-retained, implant-supported restorations. J Prosthodont 2007;16:3-9.

87. Pan YH, Ramp LC, Lin CK, Liu PR. Comparison of 7 luting protocols and their effect on the retention and marginal leakage of a cement-retained dental implant restoration. Int J Oral Maxillofac Implants 2006;21:587-592.

APPENDIX

Table 4. Raw data

	Ts	Tr	Gs	Gr	Z
1	83.09	92.25	96.61	92.49	69.03
2	83.23	92.32	96.85	107.75	71.28
3	85.16	93.27	97.69	110.44	73.09
4	89.63	93.99	100.37	121.35	76.77
5	92.65	95.86	102.28	122.02	78.65
6	96.51	98.02	102.72	125.71	82.5
7	102.72	100.32	102.89	130.75	88.6
8	111.62	101.04	108.41	138.8	98.71
9	118.12	106.58	110.27	142.32	99.46
10	118.53	109.94	113.6	152.73	109.6
Sum	981.26	983.59	1031.69	1244.36	847.69
Avg	98.13	98.36	103.17	124.44	84.77

Table 5. Statistical analysis raw data

Group 1	Group 2	Estimate	Standard Error	Raw P-value	Adjusted P-value
Gs	**Ts**	5.043	5.5694	0.37	0.8933
Gs	**Tr**	4.81	5.5694	0.3924	0.9086
Gs	**Gr**	-21.267	5.5694	0.0004	0.0036
Gs	**Z**	18.4	5.5694	0.0019	0.0153
Ts	**Tr**	-0.233	5.5694	0.9668	1
Ts	**Gr**	-26.31	5.5694	<.0001	0.0002
Ts	**Z**	13.357	5.5694	0.0207	0.1345
Tr	**Gr**	-26.077	5.5694	<.0001	0.0002
Tr	**Z**	13.59	5.5694	0.0187	0.1234
Gr	**Z**	39.667	5.5694	<.0001	<.0001