CAD/CAM Lithium Disilicate Crown Performance Cemented Extraorally and Delivered as a Screw-Retained Implant Restoration

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Dedication

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Abstract

Purpose: To determine if a novel technique combining the attributes of a cement-retained implant restoration fabricated extraorally and delivered to the patient as a screw-retained implant restoration has the necessary strength to provide a clinically acceptable and predicable restoration.

Materials and Methods: Thirty specimens were fabricated and tested in this novel implant restoration technique, in which stock abutment was scanned using a bench top laboratory scanner and 30 lithium disilicate full contour crowns were designed and milled. In the first experimental group, the occlusal access channel was prepared in a pre-sintered crown using new high-speed diamond burs in a high-speed handpiece with ample irrigation as to keep the specimen cool. The access channel was prepared by the same operator for every specimen and the diameter was recorded. The specimens were allowed to air dry for 48 hours prior to being glazed, fired and finished. In the second experimental group, the screw access channel was prepared after the crown was fired and finished. In the control group, no screw access channel was prepared. Each finished crown intaglio surface was silinated per manufacturer specifications and luted with self-adhesive resin cement to its corresponding stock abutment. The cement was allowed to cure for at least 24 hours before testing. Each specimen was individually mounted in a custom-fabricated testing fixture and tested to failure on a servo-hydraulic testing system for static and dynamic tests. Each specimen was vertically loaded at a dynamic rate of 0.100 mm/min until failure and the highest force reached at the point of failure was recorded.

Statistical analysis was performed by consultants from the Biostatistical Design and Analysis Center.

Results: A total of thirty CAD/CAM lithium disilicate crowns were fabricated and tested to failure. The first experimental group had a mean failure of 990.64N. The second experimental group had a mean failure of 1167.65, and the control group had a mean failure of 188.68N. A two-sample t-test was used to compare the load among the three groups and because there are 3 comparisons, Bonferroni method is applied to adjust p-values for multiple comparisons. The results show that experimental group #1, experimental group #2 and the control group are statistically significantly different from each other. The diameter of the screw access channel did not make a statistically significant difference, most likely because the difference among the diameter wasn't that great between samples.

Conclusions: The null hypothesis stated there will be no difference in the axial force required to fracture a lithium disilicate crown with and without a screw access channel prepared. The results of this study support rejecting the null hypothesis and accepting the alternative hypothesis. The preparation of a screw access channel in a lithium disilicate crown has statistical significance and reduces the axial load capacity from a crown without occlusal access. The diameter of the screw access channel did not make a statistically significant difference, most likely because the difference among the diameter wasn't that great between samples.

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CHAPTER 1: INTRODUCTION

There are several methods available to restore dental implants in single edentulous sites. The ideal implant restoration would take several factors into consideration including biocompatibility, ease and cost of manufacturing, ease and cost of operator impressioning and delivery, occlusion, long term maintenance and stability, low incidence of complications and patient satisfaction. When comparing screw- and cement-retained restorative solutions for single tooth replacement on a single implant, there are several advantages and disadvantages. Add into the equation the rapid technological advancements in implant dentistry including rapid prototyping, computer-aided-design/computer-aided-manufacturing (CAD/CAM), types of metals and ceramics and the workflow involved for each, the 2 basic types of restorations have a plethora of avenues to execute the final restoration.

Screw-retained implant restorations involve significant technique and time invested from a lab technician as well as several materials used in the final product that increases the lab cost, time and degree of complexity, but also provide the ultimate in retrievability. Cement-retained restorations are less costly and quicker to fabricate; however, retrievability becomes more complicated. This in vitro study will present a novel concept combining the advantages of both screw- and cement-retained implant restorations while using the most current CAD/CAM technology to restore single-unit implant crowns.

CHAPTER 2: LITERATURE REVIEW

2.1. OSSEOINTEGRATION

During the mid-1950s, Branemark[1] and his colleagues studied tissue integration of prostheses and published his landmark findings on osseointegration in 1983. The observations made in animal models involving implanted titanium chambers into bone and marrow spaces of rabbits have provided the foundation for osseointegration as it is understood today.[1] This bone-to-implant integration was further described and expanded upon by Albrektsson[2] to include a histological explanation of the interaction between titanium and bone cells. Adell[3] reported a 15-year study of osseointegrated implants which spanned from 1965 to 1980. This study was completed reviewing the implant success in completely edentulous treatment modalities while developing and evaluating a surgical protocol.[3] Maxillary prosthesis stability after 5 to 9 years was reported at 81%, and continuous stability was reported at 89%. [3] In the mandible, prosthesis stability after 5 to 9 years was reported at 91% with continuous stability reported at 100%. [3]

An early multicenter report published in 1988 by Albrektsson[4] showed 3683 implants placed by 11 teams and followed for up to 8 years. Success rates started as high as 97.38% for implants placed in the mandible and followed for 1 year to as low as 90.97% for the 1 year success rate in the maxilla.[4] Implant success criteria as described by Albrektsson[4] includes an unattached implant is clinically immobile, there is no peri-

implant radiolucency on radiograph, the vertical bone loss is less than 0.2 mm annually after the first year, and there is no clinical signs of failure including pain and infection.

2.2. IMPLANT RESTORATIONS:

A 2014 publication by Sherif[5] systematically reviewed the dental literature from 1966 through 2007 to compare major and minor outcomes between cement- and screw-retained implant restorations. Major outcomes included abutment fracture and implant failure ultimately leading to a complete restorative failure.[5] Minor outcomes involved factors that required clinician intervention including screw loosening, decementation and porcelain fractures that didn't require replacement.[5] After a database search for articles fitting the inclusion criteria, the following conclusions were reached: the major failure rate was 0.81 over 100 years, the cement-retained group was found to have a failure rate of 0.87 per 100 years and the screw-retained group was found to have a failure rate of 0.71 per 100 years.[5] These results were not statistically significant between the cement- and screw-retained restorative options.[5] When comparing 3 minor outcomes (porcelain fracture, decementation and screw loosening), there was no statistically significance between the cement- and screw-retained restorative options.[5] This systematic review concluded that both cement- and screw-retained are equally suitable for restoring patients who are partially edentulous, even though cement-retained restorations are the more common used method of implant restoration.[5]

In 2000, Belser[6] published a paper discussing the current prosthetic management of patients requiring fixed implant restorations. This paper was based off statements defined by the 1997 ITI Consensus Conference and corroborated by case examples.[6] This paper outlined 2 distinct restorative zones in the oral cavity, the esthetic zone and the non-esthetic zone, and the corresponding restorations used to restore each zone.[6] A principle in deciding implant restoration selection involves utilizing current clinical concepts regarding cost-effectiveness and predictable treatment outcomes.[6] The authors recommend utilizing a cement-retained implant restoration on a non-submerged implant where the implant platform can be easily accessed for cement removal and maintenance.[6] For the esthetic zone, a screw-retained implant restoration should be considered where the implant platform is deeper and eliminates the need for cement removal.[6]

2.2.1. SCREW-RETAINED IMPLANT RESTORATIONS

Early in modern implant dentistry, fabrication of dental restorations were attached directly to the implant platform and required elaborate laboratory procedures to complete.[7] These procedures were difficult, time consuming and lacking precision.[7] In 1988, Lewis[7] published a technique article in which they describe the rational and procedures involved in their "UCLA Abutment". They used prefabricated patterns machined to fit precisely on the implant platform with a plastic cylinder to be incorporated in the wax pattern and eliminated during the burnout process.[7] During this

time, screw-retained porcelain-fused-to-metal restorations were not popular, but a full metal casting would be completed and delivered directly to the implant platform.[7]

Sherif[8] completed a study over 5 years comparing several factors regarding cement- and screw-retained prostheses. The implant survival, defined by several factors including lack of implant mobility and infection, was not significantly different between cement- and screw-retained restorations.[8] Based on questionnaires sent to patients and returned, it was reported that patients reported greater comfort and more satisfaction with the esthetics of the cement-retained restorations over the screw-retained restorations at the time of placement.[8] These results and preferences disappeared over the 5 year duration of the study, and at the end of the evaluation, there were no statistically significant differences between the cement- and screw-retained restorations from a patient's prospective.[8]

In a 4-year split-mouth prospective study by Vigolo[9] 12 patients with 2 nearly identical bilateral sites were treated with a cement-retained implant restoration in 1 site and a screw-retained implant restoration in the other site. The results of the study demonstrated that after 4-years, there was no implant failure, no prosthetic complications, and no screw loosening between the cement- and screw-retained restorations.[9]

Work done by Hebel[10] in 1997 used anatomical average measurements for the occlusal width of posterior teeth and compared the measurements to include a 3 mm occlusal access hole for accessing the abutment screw in the screw-retained restoration. They

found the screw access channel made in the occlusal table occupied at least 50% of the occlusal surface for molars and more than 50% of the occlusal table for premolars.[10] They go on to conclude that the position of the screw access channel may be in an area necessary to have an optimum occlusal surface to provide appropriate occlusion.[10]

Retrievability was cited as a main factor when the screw-retained implant prosthesis was developed, even though at a compromise to occlusion and esthetics.[10]

A current systematic review completed by Wittneben[11] in 2014 evaluated the clinical performance of screw- and cement-retained implant restorations. In the systematic review with all the inclusion and exclusion parameters, 5,858 fixed implant restorations were followed for an average of 5.4 years.[11] Of all the restorations, 59% (3,471) were screw-retained and 41% (2,387) were cement-retained.[11] Five-year survival rates were reported as 96.03% for cement-retained restorations and 95.55% for screw-retained restorations.[11] Ten-year survival rates were estimated and reported to be 92.22% for cement-retained restorations and 91.30% for screw-retained restorations.[11] It was concluded there was no difference in survival when comparing screw- and cement-retained implant restorations.[11] It was also shown there is no difference in failure rates when comparing different types of implant restoration modalities (single crowns, fixed dental prosthesis and cantilever, and full-arch reconstructions).[11]

The ceramic fracture/chipping complication was significantly higher for screw-retained implant restorations.[11] This occurrence may be explained by the screw-access channel

weakening the surrounding ceramic or a torsional force may be applied during seating and torqueing.[11] The loosening of the abutment screw occurred significantly more for cement-retained implant restorations.[11] Overall, technical complications were found to be significantly higher for cement-retained restorations over screw-retained restorations.[11]

In vitro porcelain fracture testing comparing cement- and screw-retained crowns, Torrado[12] found the porcelain on cement-retained crowns sustained higher force to fracture than a screw-retained counterpart. It was also found the porcelain fracture resistance was not affected by the location of the screw access channel through the occlusal surface of a screw-retained implant restoration.[12]

A non-linear finite element analysis completed by Silva[13] in 2014 compared screw- and cement-retained 3-unit implant fixed dental prostheses. The screw-retained FDP had more screw loosening than the cement-retained FDP, suggesting that forces in the screw-retained FPD are transmitted to the screw and the implant, whereas the cement-retained FDP has an intermediate buffer zone of cement to reduce the force being transmitted to the screw.[13]

2.2.2 CEMENT-RETAINED IMPLANT RESTORATIONS

Cement-retained implant restoration is closely related to conventional fixed crown and bridge prosthodontics on natural teeth[14] in which a crown is cemented onto an implant abutment just like a crown is cemented on a natural tooth preparation.

By using an appropriate cement based on the desired level of retention and retrievability, cement-retained restorations can be used successfully without compromising the esthetics or occlusion.[10]

In 2002, Taylor[15] composed a paper reviewing the previous 20 years of progress in implant prosthodontics. In this paper, they cited several reasons why cement-retained implant restorations are preferred over screw-retained implant restorations.[15] One of the supporting statements included that the cemented implant restoration has no interfering screw access hole which can alter or interfere with the esthetics and occlusion.[15] Additionally, the cement-retained restoration was less costly to produce, as screw-retained implant restorations had nearly 4 times the component cost as compared to the cement-retained restoration.[15] Furthermore, a cement-retained implant restoration is more likely to achieve a passive fit as compared to a screw-retained restoration, which theorizes screw tightening a restoration creates strain on the restoration and the surrounding bone.[15] Finally, cement-retained implant restorations processes are more

similar to conventional fixed prosthodontics performed on natural teeth, which simplifies the process for the restorative dentist.[15]

A 2013 three-dimensional profilometric analysis completed by Cresti[16] examined the margination of CAD/CAM-produced lithium disilicate crowns on the titanium abutment of cement-retained implant restorations with the assumption microgap discrepancies would lead to peri-implantitis. It was concluded that if there was a microgap present, resin cement would fill in the void but it would be difficult to polish the margin intraorally. Screw-retained implant restorations have the advantage to have the titanium-lithium disilicate margin polished in the laboratory.[16]

3. BIOLOGICAL AND STRUCTURAL IMPLICATIONS

Wilson in 2009 evaluated 39 consecutive patients with 42 implants over a 5 year period that presented with suppuration or bone loss (clinically or radiographically) associated with restored dental implants.[17] Endoscopic evaluation of these cement-retained implant restorations confirmed the suspicion of excess cement being retained subgingivally and representing a foundation for bacterial colonization.[17] The results of this study found retained cement was associated with 34 of the 42 implants, which represents 80.95%.[17]

According to a series of cases reported and published by Wadhwani[18] in 2012, they found that residual excess cement could be detected on any depth of margin into the sulcus. In this study, they classified and quantified the location of residual excess cement in relation

to the margin position at a specified depth into the soft tissue sulcus.[18] It was shown that margins ranging in depth from 2 mm to 3 mm into the soft tissue showed the greatest cement excess weight of any other margin depth range.[18] One of the cases reported showed a lack of fully seating a final restoration, which increased the marginal gap significantly and allowed for a greater amount of excess cement to be extruded.[18]

Linkevicius[19] completed an in vitro study to evaluate how the margin location influenced the amount of undetected cement retained after delivery of a cement-retained crown restored on a dental implant. During the study, they found retained implant cement on all restorations to some degree and described how difficult it is to remove excess cement.[19] Margin depth had a direct correlation to the amount of retained excess cement and the greatest amount of cement excess was left when the crown/abutment margin was 2 mm to 3 mm below the gingival crest.[19] The only time all the cement remnants were able to be removed was when the entire crown/abutment margin was clinically visualized.[19]

Following the in vitro study in 2011, Linkevicius[20] continued their research and published a prospective clinical study in 2013 to evaluate the influence of margin position and the amount of undetected cement. Through the evaluation, they found various degrees of remaining excess cement on all retrieved restorations.[20] This in vivo study corroborated the previous study findings in which a sulcular margin depth of 2 mm to 3 mm was where the most residual excess cement was found clinically.[20] It was also

noted that the residual cement not only adhered to the restoration and/or abutment, but also adhered to the sulcus tissue.[20]

The restoration margin was shown by Cosyn[21] to be a principle avenue for bacterial leakage and contamination. By using checkerboard DNA-DNA hybridization, pathogens associated with peri-implantitis were found in the in the peri-implant sulcus, the implant compartment and the suprastructure compartment.[21]

Before the Cosyn study, Quirynen[22] in 1993 evaluated the presence of microorganisms along the inner aspect of the threads of a dental implant using differential phase-contrast microscopy. Bacteria representing coccoid cells were found in abundance in the internal aspect threads of the external hex dental implant.[22] This significant presence of microorganisms in this portion of the implant system indicates these bacteria may have come from an initial baseline contamination, contamination of the abutment screw during removal or leakage of the abutment/implant margin.[22] The most likely cause for this bacterial colonization of the internal aspect of the dental implant is from the leakage of the marginal gap between the implant and abutment.[22]

Keller[23] in 1998 compared the microbiotic flora surrounding screw- and cement-retained restorations on dental implants. Periodontal clinical evaluation and histological evaluation of patients with dental implants were completed.[23] Their study concluded that marginal gaps between abutments and screw-retained restorations are sites of bacterial

colonization.[23] They also concluded the type of restoration (comparing cement- and screw-retained restorations) had little influence on the microbiological parameters.[23] Another way to summarize this finding is the same bacterial pathogens colonize cement-retained and screw-retained restorations in the same manner and certain bacteria do not have a higher or lower affinity for binding to a specific type of implant restoration.[23]

The differences between cement- and screw-retained implant restorations were hypothesized to be significantly different at a soft tissue cellular level.[24] A 2006 animal study placed implants and looked for differences between the 2 implant restoration modalities involving vascular endothelial growth factor (VEGF) expression, microvessel density (MVD), proliferative activity (MIB-1), and inflammatory infiltrate surrounding the soft tissue using immunohistochemical evaluation.[24] There was no statistically significant difference on an immunohistochemical level between cement- and screw-retained implant restorations when evaluating the mentioned biologic markers for cell and blood vessel growth and inflammation.[24] It was noted when there was a screw loosening of the abutment to the implant connection, there was high intensity increase in VEGF, which can be explained by bacteria leaking into the surrounding tissues.[24]

In a multicenter, 3-year prospective study completed by Weber[25] in 2006, 152 implants were placed in 80 patients and followed for 3 years. Fifty-nine (38.82%) of the crowns were cement-retained restorations while the remaining 93 (61.18%) of the implant restorations were screw-retained.[25] Modified plaque index, sulcus bleeding index,

keratinized mucosa, gingival level and esthetic fulfillment was followed at initial loading, 3 months, 6 months, 12 months, and 36 months after loading.[25] It was found the cement-retained implant restorations had a worsening trend regarding modified plaque scores and sulcus bleeding index.[25] It was also shown the screw-retained implant restorations had the opposite result, in which the modified plaque scores and sulcus bleeding index improved over the study time frame.[25] No soft tissue recession was noted in either of the implant restorative modalities, and patients reported being equally satisfied with either type of implant restoration.[25]

Marginal discrepancy between 2 implant restorative modalities was examined in an in vitro study completed by Keith in 1999.[14] Implant to abutment/crown margin gap was evaluated for screw- and cement-retained single-unit implant restorations.[14] It was found the screw-retained metal-ceramic restoration had a marginal gap ranging from 82.7 to 88.9μm, depending on if a new gold cylinder or a cast gold cylinder was used in the fabrication.[14] The marginal gap for the cement-retained restoration ranged from 112.2 (+/- 33.5) to 147.3 (+/- 17.3) μm depending on the type of cement used.[14]

A 4-year prospective study was completed to evaluate if a difference in peri-implant tissue health existed between titanium and gold-alloy abutments when single implant crowns were cemented to the abutments.[9] Forty implants were restored in 20 patients in this split-mouth study design in which each patient received a titanium abutment and a gold-alloy abutment, each with a corresponding metal-ceramic cement-retained

restoration.[9] Clinical parameters including plaque and gingival inflammation, bleeding on probing, keratinized gingiva, and marginal bone levels were monitored for 4 years and it was concluded there was no difference in bone or peri-implant soft tissue response between the titanium and gold-alloy abutment material when a crown is cemented as the final restoration.[9]

Biologic complications were reported to be significantly higher for cement-retained implant restorations as reports by a systematic review completed by Wittneben[11]. The cement-retained restorations presented more often than the screw-retained restorations with fistula formation and suppuration.[11] When other biologic complications were compared, including bone loss greater than 2 mm, peri-implant mucositis, fistula/suppuration, recession, and total implant loss, there was no statistically significant difference between cement- and screw-retained implant restorations.[11]

Screw- and cement-retained implant abutment restoration research was taken a step further in evaluation of screw loosening by comparing screw-connected abutments to dental implants and cement-connected abutments to implants in an animal study completed by Assenza.[26] Sixty implants were placed in 6 beagle dogs in a split-mouth designed study.[26] Within each dog, 5 implants were restored with abutments screwed into the implant and 5 implants had the abutment cemented directly into the implant connection.[26] Fixed dental prostheses were cemented over the abutments and evaluated

after 12 months.[26] After the evaluation period, they found 8 (27%) of the screws were loose, whereas none of the cemented abutments were loose.[26]

The influence of a screw-access channel through a porcelain-fused-to-metal implant restoration has been hypothesized to decrease the cement-retention level on an implant restoration.[27] An in vitro study comparing cement-retained metal-ceramic implant crowns made with and without a screw access channel casted into the metal framework concluded that the screw access channel did not make a difference in the amount of force needed to dislodge the crown from the abutment.[27]

4. PROSTHETIC MANAGEMENT OF IMPLANT CROWNS

A 2012 systematic review completed by Gracis[28] compared internal and external connections for implant and abutment systems found the most frequent complication between both systems was screw loosening. This review concluded a 3-year cumulative incidence of screw loosening of 1.5% for internal connection implants and 7.5% for external connection implants.[28] In respect to abutment screw fracture, the study concluded a 0% incidence following a 3-year reporting period.[28]

Several consensus statements were reviewed and published by Wismeijer[29] in 2013 regarding restorative materials and techniques. Both screw- and cement-retained implant restorations have advantages and disadvantages including ease of fabrication, retention,

costs and complications.[29] Cemented metal-ceramic implant restorations perform better and have higher success than do cemented all-ceramic implant restorations.[29] When comparing screw- and cement-retained implant restorations, both exhibit technical complications; however, the cemented restorations had a higher rate of complications when the data was pooled.[29] Screw-retained restorations have a higher incidence of ceramic chipping when compared to cement-retained restorations.[29] Cement-retained restorations have a higher incidence of biologic complications including fistula formation and suppuration as compared to screw-retained restorations.[29]

Lee[30] in 2013 completed a photoelastic stress study comparing the stress involved in screw- and cement-retained implant restorations in which the stress is transmitted to the crestal bone. They tested screw- and cement-retained implant restorations with and without a gap between the implant platform and the abutment.[30] When the restorations were connected tightly to the implant platform, thus minimizing the marginal gap, there was a minimal amount of stress transmitted to the crestal bone.[30] When terminal implants were loaded, the stress distribution was similar for screw- and cement-retained restorations.[30] When a fixed dental prosthesis restoration was tested, the screw-retained prosthesis with marginal gaps had the widest range of stress on the implant.[30]

A systematic review published in 2008 regarding 5-year survival and complications involving implant-supported single unit restorations found the 5-year survival of metal-ceramic implant crowns was 95.4%, while all-ceramic crowns had a 5-year survival of

91.2%. [31] This study also reported the most common technical complication was abutment screw loosening, which was reported at 12.7% at 5 years.[31] The second most common technical complication was loss of retention, reported at 5.5% after 5 years.[31] Fracturing of veneering ceramic or acrylic was reported at the third most common technical complication at 4.5% after 5 years.[31]

A follow up systematic review was published by the same authors in 2012, looking at the same survival rate incidences of common complications.[32] The 5-year survival rates for metal-ceramic and all-ceramic implant crowns as reported in this 2012 review were equal at 95.8%. [32] Technical complications such as screw loosening was reported at 8.8%, loss of retention at 4.1%, and fracture of veneering material at 3.5% after 5 years.[32]

A technique and opinion paper published by Milin[33] in 2010 was the only paper found which experimented with combining attributes and properties of screw- and cemented retained implant crowns. In this paper, the author would use a metal-ceramic crown prepared with a screw access channel on the occlusal surface and mate it to a stock abutment.[33] The crown was cemented and polished extraorally and delivered to the patient as a screw-retained implant restoration.[33]

5. LITHIUM DISILICATE

Lithium disilicate ceramic material was first classified as a glass-ceramic by Stookey in 1959.[34] Glass-ceramics exist in 2 phases (a biphasic material) composed of an amorphous phase and a crystalline phase.[34]

Biskri[35] in 2013 computationally studied several properties of lithium disilicate including structural, elastic, and electronic properties. Through mathematical computation, they concluded the results they achieved were in agreement with experimental data.[35] They also concluded that lithium disilicate is brittle in nature, stable against elastic deformation, and possesses a lower anisotropy.[35]

An in vitro study on natural tooth preparations in 2014 comparing the fatigue resistance of CAD/CAM produced lithium disilicate, resin nanoceramic and feldspathic glass ceramic, found lithium disilicate and resin nanoceramic to outperform feldspathic glass ceramic.[36] Lithium disilicate was the best performing material when comparing survival rates in the experiment to the other types of restorative materials.[36] Reported survival rates were: lithium disilicate was 93.9%, resin nanoceramic was 80%, and feldspathic glass ceramic was 6.6%.[36]

In 2011, Kelly[37] completed a review of dental ceramics and described the historical and present evolution of these materials being used in the oral cavity. A new era in porcelain

restorations arose in 1962 with the development of a ceramic that could be fired upon a metal casting alloy, giving us the porcelain-fused-to-metal dental restoration.[37] Porcelain has made many transformations to the options that are available in dentistry today.[37] They are used for their biocompatibility, chemical durability, and the ability to replicate the optical characteristics of natural teeth.[37]

5.1. LITHIUM DISILICATE AND CLINICAL IMPLICATIONS

Pressed and computer-aided design/computer-aided manufacturing (CAD/CAM) ceramic crowns were evaluated by Anadioti in 2014.[38] All ceramic, pressed, lithium disilicate crowns were fabricated from impressions made digitally (using an intraoral scanner and allowing for a stereolithographic model to be fabricated) and conventionally using polyvinyl siloxane in a custom tray (with conventional type IV dental die stone being used for model fabrication). [38] Standardized wax patterns were made and invested, and the final crown fit was evaluated.[38] The largest fit discrepancy was found between the intraoral scanner and the pressed lithium disilicate crown.[38]

Lithium disilicate crowns have 2 techniques of fabrication, computer-aided design/computer-aided manufacturing or heat pressing involving a derivation of the lost wax technique.[39] When using a chair-side milling machine, the results show the marginal adaptation of the pressed lithium disilicate greatly outperformed the CAD/CAM produced lithium disilicate crown, when used to restore a natural tooth.[39]

Heintze[40] completed an in vitro study in 2007, around the same time that IPS eMax press lithium disilicate crowns come to the dental market. Previously, IPS Empress 2 was the popular pressable lithium disilicate crown in the dental marketplace, which was an all-ceramic crown with higher mechanical strength than previous all-ceramic crowns, but was quite opaque.[40] In this study, 144 IPS Empress 2 lithium disilicate crowns and 144 IPS eMax Press lithium disilicate crowns were produced and tested to failure in a simulated chewing machine.[40] The results found out of the 144 IPS Empress 2 crowns, there were 9 complete fractures and 3 partial cracks, which represents a fracture frequency of 6.25% and a crack frequency of 2.1%.[40] The IPS eMax Press lithium disilicate crowns had no fracture or crack events at all.[40]

A 2014 study by Dhima[41] followed single ceramic crowns for at least 5 years in a practice-based setting. 226 single crowns on natural teeth and implants were followed for an average of 6.1 years in 59 patients.[41] Of the total 226 crowns followed for this study, 27 (12%) experienced fractures with 17 (63%) of these fractures extending to the core.[41] It was also reported that the replacement-free survival rates for the ceramic restoration involving single crowns was 95.1% at 5 years and 92.8% at 10 years.[41] Due to the fracture nature of layered ceramic failure extending to the core of the restorations, the authors suggest more consideration given to monolithic ceramic systems over layered ceramics with a core.[41]

Dhima[42] hypothesized and published a paper in 2014 regarding lithium disilicate performance at varying thicknesses of material tested in an aqueous environment. They produced lithium disilicate single unit crowns on standardized tooth preparations and evaluated thicknesses of 0.5 mm, 1.0 mm, 1.5 mm, and 2.0 mm.[42] All the crowns underwent the same dynamic loading to fatigue in an aqueous environment.[42] The results showed that 0.5 mm of lithium disilicate restorative material performed the worst and failed after 1 testing cycle.[42] The crowns restored with 1.5 mm and 2.0 mm thick lithium disilicate crowns performed better than the 1.0 mm crowns, in which the researchers concluded a milled monolithic lithium disilicate crown should have a minimum thickness of 1.5 mm of restorative material to offer satisfactory performance.[42]

Comparing edge chipping and flexural resistance of monolithic ceramics, Zhang[43] found that IPS e.max Press has a slightly higher toughness than IPS e.max CAD due to grain size and shape. While being less esthetic, monolithic zirconia had higher resistance to failure over lithium disilicate glass-ceramic.[43] Monolithic lithium disilicate ceramic crowns out performed lithium disilicate glass-ceramic layered over zirconia core restorations.[43]

A German study published in 2012 by Kern[44] placed lithium disilicate fixed dental prostheses and followed them at regular intervals for 10 year. At the initial observation, they had placed 36 all-ceramic lithium disilicate FDP's in 28 patients.[44] At the end of the 10 year study, they reported overall 4 failures (1 biological and 3 technical) and 11

complications (2 biological and 9 technical) occurring in 15 FDPs.[44] When comparing the lithium disilicate results to published data on metal-ceramic FDP's, the authors conclude the survival and success rates to be similar at the 5 and 10 year time durations.[44]

When CAD/CAM produced metal-ceramic, all-ceramic lithium disilicate, and zirconia crowns were compared in a 2014 in vivo study by Batson, the results show there was no statistical significant difference between the 3 types of CAD/CAM crowns when looking at bleeding on probing and gingival crevicular fluid volumes.[45] There were significant differences in the 3 types of crowns when using micro-CT technology to measure the horizontal marginal discrepancy, which showed lithium disilicate CAD/CAM all-ceramic crowns had a larger discrepancy than the CAD/CAM zirconia crowns.[45]

A 2014 systematic review completed by Pieger[46] reported the tooth-born lithium disilicate crown cumulative survival rate for 2 years was 100% and for 5 years was 97.8%. The 10-year cumulative survival rate was 96.7% for single crowns, but this data was collected from only 1 study.[46]

SPECIFIC AIM

To evaluate the effect of a screw access channel prepared in a lithium disilicate crown cemented extraorally on a stock titanium implant abutment and delivered as a screw-retained restoration.

STATEMENT OF THE PROBLEM

Retained cement near the implant platform has been proven to be a significant factor for bone loss around an implant and implant failure. To eliminate this potential site for bacterial colonization and destruction, cement should be used either sparingly or eliminated by using a screw-retained implant restoration as an alternative to cement retention. A UCLA style screw-retained implant restoration corrects the concern for cement retention, but increases laboratory costs and is more technique sensitive to fabricate. To combine the benefits of screw- and cement-retained crowns, a crown fabricated with a screw-access hole and cemented extraorally on a stock abutment has been proposed as an alternative restorative technique.

GENERAL OBJECTIVE

The objective of this study was to compare the strength of lithium disilicate crowns when prepared with and without a screw access channel through the occlusal surface of the crown. This study will provide objective data and clinical recommendations regarding the use of cement-retained lithium disilicate crowns delivered as a screw-retained restorative solution.

SPECIFIC OBJECTIVE

The specific objective of this study was to manufacture CAD/CAM lithium disilicate crowns and use a servo-hydraulic axial torsion load frame to test them under compression until failure. One experimental group had a screw access channel prepared in the lithium disilicate crown before the crown was fired in a porcelain oven. The second experimental group had the screw access channel prepared after the crown was fired. The control group did not have a screw access channel prepared in the occlusal aspect of the lithium disilicate crown. Statistical analysis was completed to compare the groups and verify if the screw access channel compromised the performance of the crown. The diameter of the access channel will also be analyzed to report any statistical significance.

NULL HYPOTHESIS (H_0)

There will be no statistically significant difference in the axial force required to fracture a lithium disilicate crown with or without a screw access channel prepared.

ALTERNATIVE HYPOTHESIS (H_1)

There will be a statically significant difference in the axial force required to fracture a lithium disilicate crown with or without a screw access channel prepared.

CHAPTER 3: MATERIALS AND METHODS

Thirty specimens were fabricated and tested in this novel technique (2 experimental groups and 1 control group) (Figure 1). Given the apparent uniformity of stock abutments within acceptable parameters for this study, 1 abutment was scanned and 1 crown was designed and then milled 30 times. This was done to ensure uniformity in the crown design among each specimen.

An implant replica with conical connection for a regular platform implant (Nobel Biocare, Yorba Linda, CA) was used to mount a stock abutment (Snappy Abutment 5.5 Conical Connection RP 1.5 mm collar height, Nobel Biocare). The stock abutment was scanned using a bench top laboratory scanner (Nobel Procera, Nobel Biocare). A crown for a mandibular right first premolar was digitally designed in the computer software to provide an anatomically minimal, yet clinically appropriate amount of restorative material to restore the crown. The occlusal region of the crown was designed anatomically accurate and to allow for 2.0 mm of restorative lithium disilicate. The axial wall thickness ranged from 0.5 mm at the implant platform to 1.5 mm near the occlusal aspect of the restoration (Figure 2, Figure 3, Figure 4, Figure 5, Figure 6). Once the crown was digitally visualized and confirmed to be of adequate size and contour, 30 crowns (Procera IPS eMax) were milled from the same digital CAD file. The lithium disilicate crown fabrication was completed in this fashion in order to eliminate any variation from specimen to specimen. Thirty crowns were returned from the milling

center (Nobel Procera, Nobel Biocare), evaluated for margination, anatomy, abutment fit and overall quality while in the pre-sintered, or "blue" state (Figure 7).

In the first experimental group, an occlusal access channel was prepared in 10 pre-sintered crowns using high speed diamond burs in a high speed handpiece (Brasseler USA Dental, Savannah, GA) with ample irrigation as to keep the specimens cool. The access channel was prepared by the same operator for every specimen and the diameter was recorded with a digital caliper (Mitutoyo Digital Caliper; Mitutoyo America, Aurora, IL). The specimens were allowed to air dry for 48 hours prior to finishing. Crowns were glazed (IPS eMax CAD glaze; Ivoclar Vivadent, Amherst, NY) and fired in a ceramic furnace (Vita Vacumat 40; Vita, Bad Säckingen Germany) (Figure 8). After sintering, the intaglio surfaces of the crowns were silinated (Porcelain Etch Gel and Silane Bond; Pulpdent Corporation, Watertown, MA) per manufacturer specifications was and then luted with self-adhesive resin cement (RelyX Unicem; 3M ESPE, St. Paul, MN) to its corresponding stock abutment. The resin cement was allowed to cure for at least 24 hours before testing.

Ten crowns in the second experimental group were glazed (IPS eMax CAD glaze; Ivoclar Vivadent) and fired in a ceramic furnace (Vita Vacumat 40; Vita). The occlusal access channel was prepared in these 10 crowns using diamond burs in a high speed handpiece (Brasseler USA Dental) with ample irrigation as to keep the specimens cool. The access channel was prepared by the same operator for every specimen and the diameter was

recorded with a digital caliper (Mitutoyo Digital Caliper; Mitutoyo America). Each finished crown intaglio surface was silinated (Porcelain Etch Gel and Silane Bond; Pulpdent Corporation) per manufacturer specifications. Each crown was luted with self-adhesive resin cement (Rely-X Unicem, 3M ESPE) to its corresponding stock abutment (Figure 9, Figure 10). The cement was allowed to cure for at least 24 hours before testing.

No screw access channel was prepared in these ten specimens. These crowns were glazed (IPS eMax CAD glaze; Ivoclar Vivadent) and fired (Vita Vacumat 40 (Vita, Bad Säckingen Germany)). Each finished crown intaglio surface was silinated (Porcelain Etch Gel and Silane Bond; Pulpdent Corporation) per manufacturer specifications. Each crown was luted with self-adhesive resin cement (Rely-X Unicem, 3M ESPE) to its corresponding stock abutment. The cement was allowed to cure for at least 24 hours before testing.

Each specimen was individually mounted in a custom-fabricated testing fixture (Figure 11, Figure 12, Figure 13) and tested to failure on a servo-hydraulic testing system for static and dynamic tests (MTS 858 Mini Bionix II; MTS Systems Corporation, Eden Prairie, MN) in the Minnesota Dental Research Center for Biomaterials and Biomechanics (Figure 14, Figure 15). The lower portion of the instrument is a sensitive load-testing cell; the upper portion (Figure 16) is a 3 mm diameter round tool steel on the end of a precision hydraulic ram (Figure 17, Figure 18). Each specimen was vertically

loaded at a dynamic rate of 0.1 mm/min until failure (Figure 19, Figure 20). The highest force reached at the point of failure was recorded in Table 1.

Figure 1. Crown Stages Compared

Figure 2. Digital Design for CAD/CAM Lithium Disilicate (1)

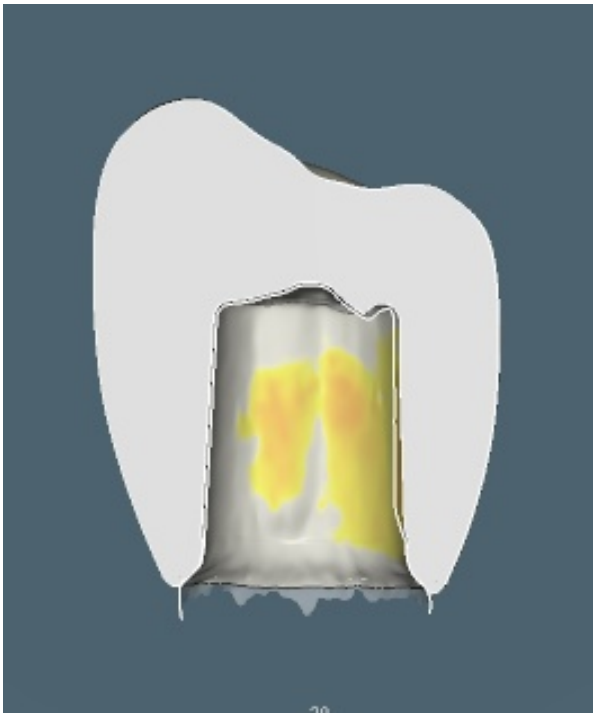

Figure 3. Digital Design for CAD/CAM Lithium Disilicate (2)

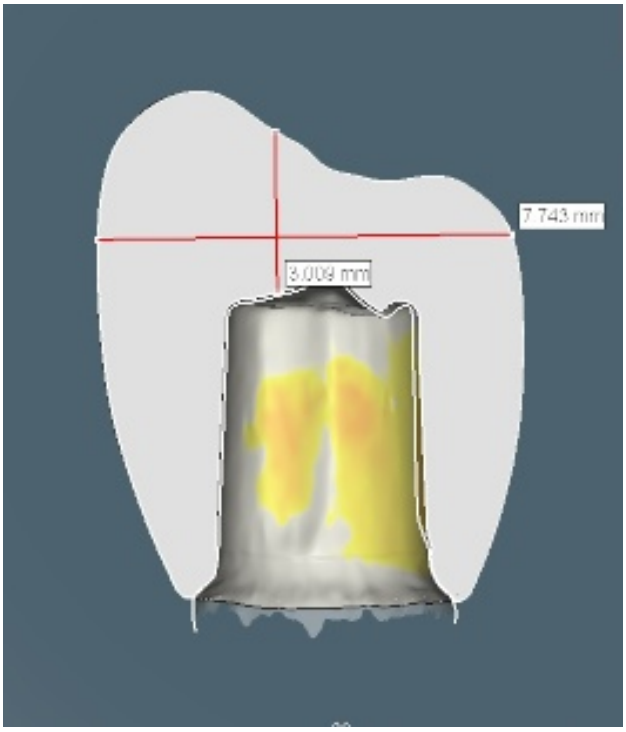

Figure 4. Digital Design for CAD/CAM Lithium Disilicate (3)

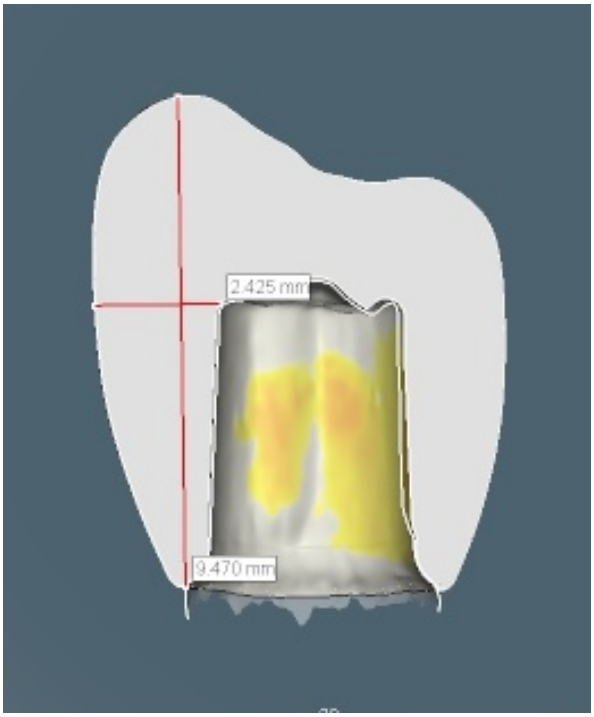

Figure 5. Digital Design for CAD/CAM Lithium Disilicate (4)

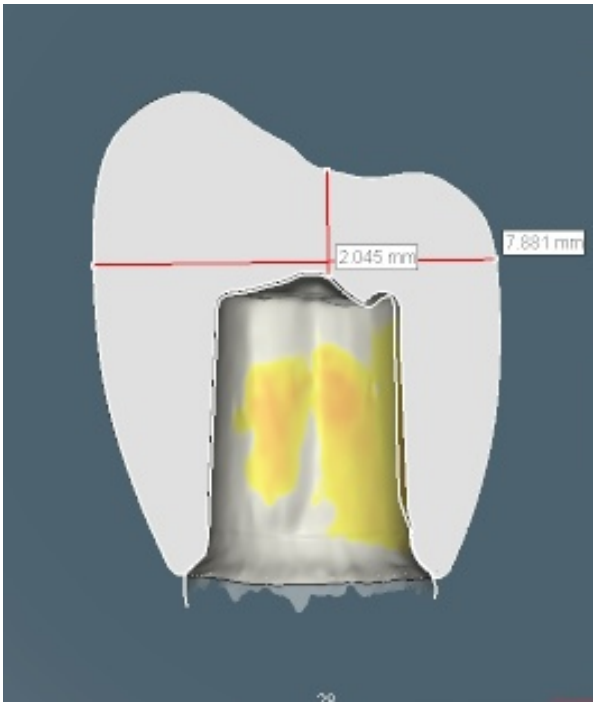

Figure 6. Digital Design for CAD/CAM Lithium Disilicate (5)

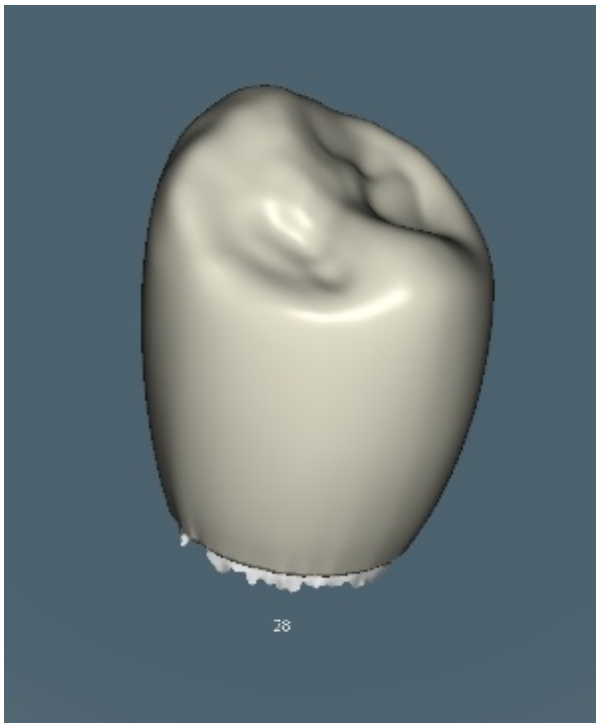

Figure 7. Pre-Sintered Lithium Disilicate Crown

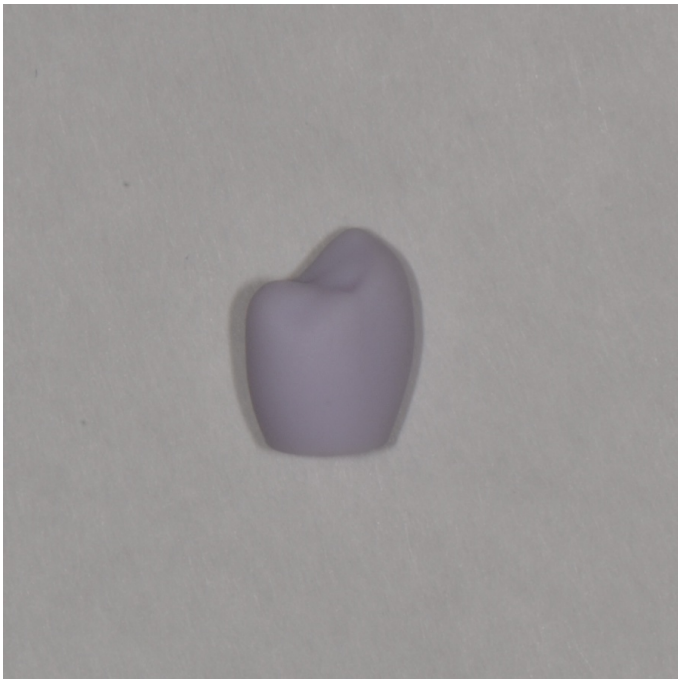

Figure 8. Sintered and Finished Lithium Disilicate Crown

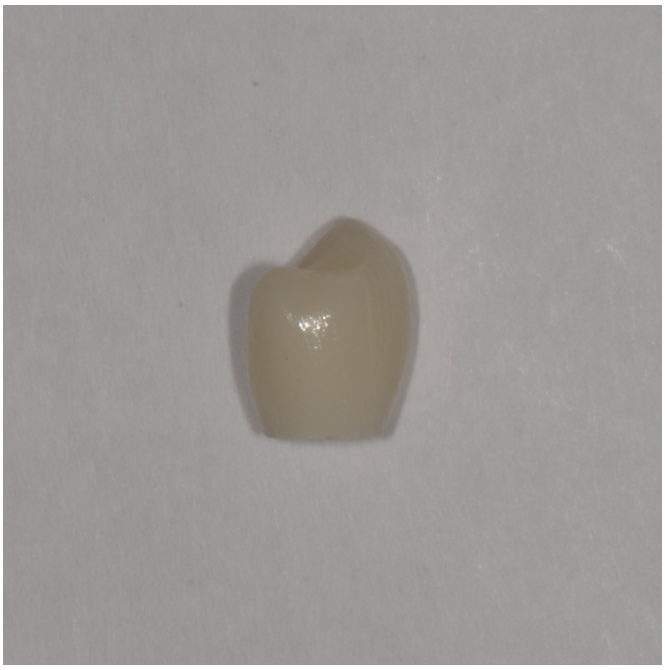

Figure 9. Sintered and Finished Lithium Disilicate Crown with Screw Access

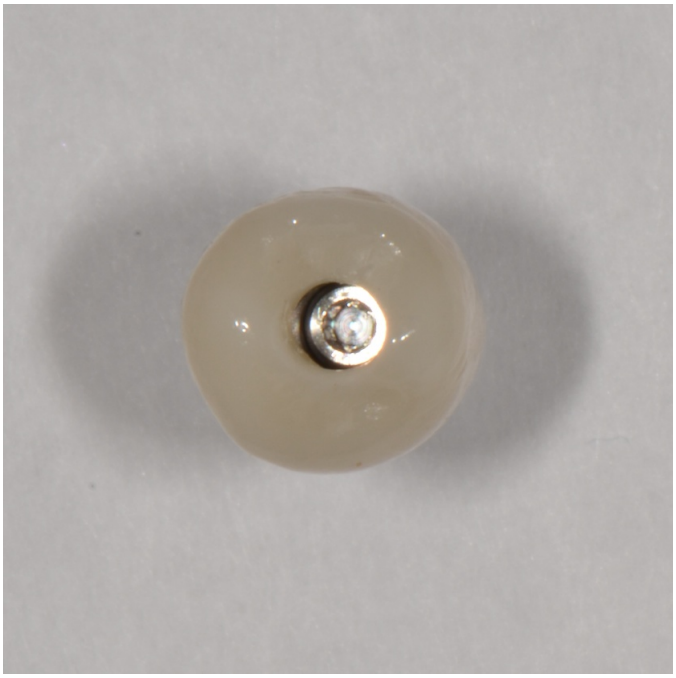

Figure 10. Finished Lithium Disilicate Crown Cemented to Stock Abutment

Figure 11. Custom Mount for Implant Replica For Use in MTS Testing Machine

Figure 12. Custom Mount with Implant Replica

Figure 13. Finished Crown/Abutment Mounted in Testing Mount for MTS Machine

Figure 14. MTS 858 Mini Bionix II Servo-Hydraulic Testing System

Figure 15. MTS Load Cell and Hydraulic Ram

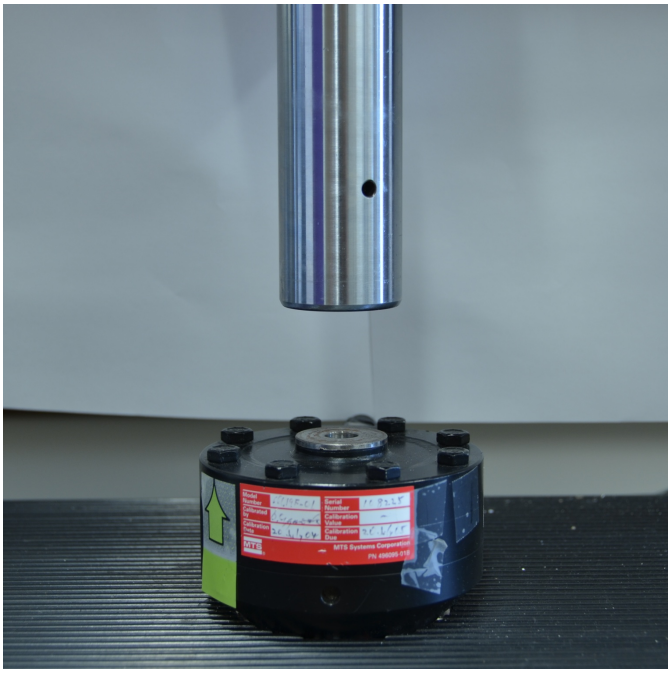

Figure 16. Custom Testing Antagonist for Use in MTS Testing Machine

Figure 17. MTS Machine Setup for Testing

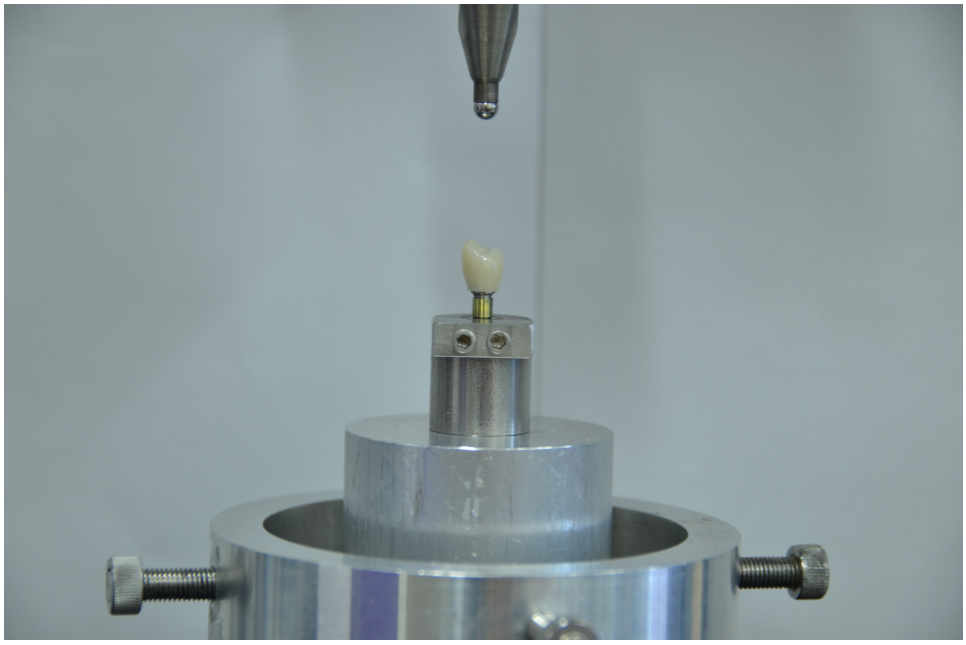

Figure 18. Hydraulic Ram in Place Ready to Test

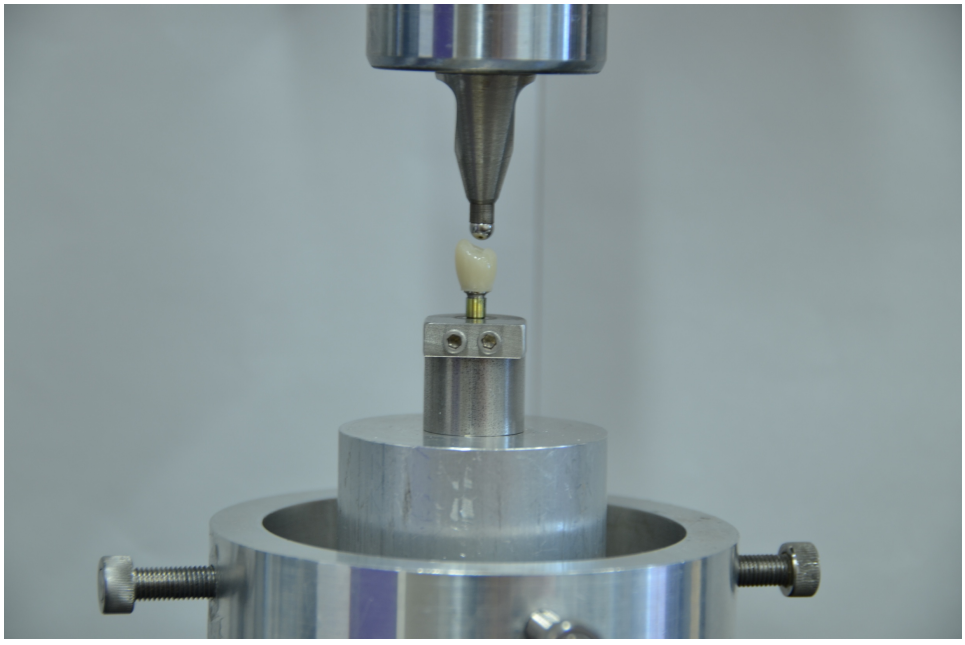

Figure 19. Lithium Disilicate Crown Fracture Pattern (1)

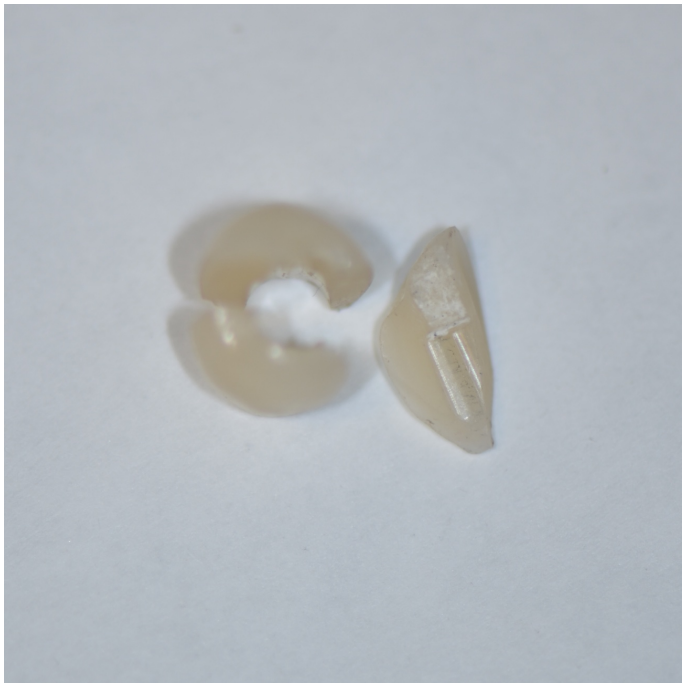

Figure 20. Lithium Disilicate Crown Fracture Pattern (2)

Table 1. Experimental Group #1:
Occlusal Access Prepared in Pre-sintered Crown

Sample	access hole (mm)	axial load (N)
1	2.81	862.25
2	2.76	1070.85
3	2.68	1033.75
4	2.66	1026.41
5	2.72	1041.35
6	2.76	956.08
7	2.72	1014.14
8	2.74	1010.92
9	2.78	1000.06
10	2.78	890.62

Table 2. Experimental Group #2:
Occlusal Access Prepared in Finished Crown

Sample	access hole (mm)	axial load (N)
1	2.7	1392.50
2	2.74	1308.57
3	2.67	989.65
4	2.65	1322.21
5	2.66	1064.85
6	2.76	1082.48
7	2.67	1323.01
8	2.73	1005.60
9	2.78	1240.26
10	2.74	947.36

Table 3. Control Group:
No Occlusal Access Prepared in Crown

Sample	access hole (mm)	axial load (N)
Control 1	0	1394.27
Control 2	0	1668.78
Control 3	0	2093.95
Control 4	0	2088.75
Control 5	0	2441.40
Control 6	0	1970.41
Control 7	0	1417.34
Control 8	0	2181.57
Control 9	0	2007.68
Control 10	0	1622.62

A 2-sample t-test was used for comparison of load to failure among the 3 groups. Because there are 3 comparisons (AB, AC and BC), the Bonferroni method is applied to adjust *P*-values for multiple comparisons. So the *P*-value = 0.05/3 = 0.0167 is considered as statistical significance in this analysis.

CHAPTER 4: RESULTS

The null hypothesis stated there would be no difference in the axial force required to fracture a lithium disilicate crown with and without a screw access channel prepared. The results of this study support rejecting the null hypothesis and accepting the alternative hypothesis. A total of 30 specimens were load tested to failure. The two most common modes of failure are represented in figure 19 and figure 20, in which failure was produced through the central groove (the weakest point). The results are summarized below.

Table 4. Summary Descriptive Statistics:

group	n	mean (N)	SD	Median (N)	minimum (N)	maximum (N)
experimental #1	10	990.64	67.3928	1012.53	862.25	1070.85
experimental #2	10	1167.65	166.0008	1161.37	947.36	1392.5
control	10	1888.68	346.4165	1989.04	1394.27	2441.4

A 2-sample t-test was used to compare the load among the 3 groups and because there are 3 comparisons (AB, AC and BC); Bonferroni method was applied to adjust *P*-values for multiple comparisons. So the *P*-value = 0.05/3= 0.0167 is considered as statistical significance in this case. The results show that experimental group #1, experimental group #2 and the control group are statistically significantly different from each other. The *P*-values are all less than 0.0167.

Table 5. Comparison of load among the three groups:

Comparison	Difference	SD	*P*-value
exp. #1 to exp. #2	-177	56.7	0.0089
exp. #1 to control	-898	111.6	<0.0001
exp. #2 to control	-721	121.5	<0.0001

The preparation of a screw access channel in a lithium disilicate crown has statistical significance and reduces the axial load capacity from a crown without occlusal access. The diameter of the screw access channel did not make a statistically significant difference, most likely because the difference among the diameter was not large between samples.

Table 6. Comparison the screw access channel diameter among the 3 groups:

Effect	Group	Estimate	Standard Error	Pr > |t|
Intercept		3192.32	1728.02	0.0822
Group	Exp #1	-153.84	59.4565	0.0192
Group	Exp #2	0	.	.
Size		-747.11	637.48	0.2574

After adjusting for the access hole size, experimental group #1 is still less strong than experimental group #2. The difference is 153.84, and *P*-value is 0.0192. The diameter of the hole seems negatively associated with load, but it did not reach statistically significance.

CHAPTER 5: DISCUSSION

The results of this in vitro study support rejecting the null hypothesis that there will be no difference in the axial force required to fracture a lithium disilicate crown with and without a screw access channel prepared. The alternative hypothesis that there will be statically significance in the axial force required to fracture a lithium disilicate crown with and without a screw access channel prepared was accepted.

Research involving in vitro testing of lithium disilicate crowns modified and delivered as a screw-retained implant restoration has not been done before under the experimental control and data acquisition of this study. The technique and opinion paper published by Milin[33] in 2010 only described a technique, which was delivered to a patient. This was purely opinion of the author and the procedure was completed with no further clinical or research evidence basis. There were no material testing, wear studies, or follow-up patient data. Many providers are delivering this type of implant restoration with no evidence it is a safe and effective restoration, even though a certified dental laboratory is fabricating it for the clinician.

This is the first study to evaluate this implant restorative option and substantiate statements made using clear scientific data acquired under controlled conditions and the statistics were analyzed to support a final conclusion and clinical recommendation to practitioners.

Studies up to this point in time have shown clinical success of both conventional screw- and cement-retained implant restorations. Both restoration modalities show high clinical success, with no statistically significant difference between the two.[5] When comparing minor complications including decementation, porcelain fracture and screw loosening, there is also no difference in the 2 treatment restorations.[5]

Cement-retained implant restorations are more often chosen due to the reduced cost to fabricate, the ability to achieve passivity in the system and the thought they may be easier to deliver as this restoration is similar to restoring conventional crowns on natural teeth.[15] This study and treatment modality was selected as a simpler and more cost effective way to deliver a cement-retained implant restoration as a screw-retained restoration to capitalize on the positive attributes of each system. The positive attributes of the screw-retained implant restoration include retrievability and no chance of having residual cement. The positive attributes of the cement-retained restoration are cost of manufacturing and materials and more passivity than a screw-retained restoration. Disadvantages of screw-retained restorations include the presence of an occlusal access channel that may weaken the porcelain and decreased passivity of the prosthesis. Disadvantages of cement-retained restorations include the potential for residual cement, increased marginal gap[14], and decementation.

Cost of fabrication was a main purpose of this study, to see if a cost-effective restoration could be delivered with the same clinical success and predictability as a more costly technique to fabricate an implant restoration. Screw-retained implant restorations can be

almost 4 times the cost of components and fabrication than cement-retained implant restorations.[15] Screw-retained restorations require a UCLA wax-to cylinder with restorative screw, a significant metal cost, porcelain, and the man-hours of a skilled laboratory technician to successfully plan and fabricate this restoration. The cost of this restorative modality can vary with the dynamic costs of precious metals and the increase in labor costs. A cement-retained implant restoration requires an abutment (either stock or custom) and screw, a crown and cement. Costs of the cement-retained implant restoration may vary with the use of a stock or custom abutment, and the choice of crown restorative material.

Stock and custom abutments each have their roles in implant dentistry. The custom abutment allows for better control of the soft tissue emergence profile, but this ability comes at an increased cost. Stock abutments lack the ability to control the emergency profile and lack resistance and retentive form, but are much lower in cost that the custom abutment. This study was designed using a 5.5 mm tall stock abutment, which would allow the increase in axial wall height to increase the resistance and retentive form. This specific stock abutment also had anti-rotational features milled into the surface. The stock abutment chosen for this study also had the shortest implant platform-to-margin distance, at 1.5 mm. This allowed the CAD/CAM crown to be designed in such a way so the proper soft tissue emergence profile was achieved by using the support of the porcelain, not the metal of the abutment.

Since this implant restoration was cemented extraorally, all excess cement would be removed extraorally, prior to delivering the restoration.

The CAD/CAM process of crown fabrication was a key feature in keeping the cost of this novel implant restoration low. The digital wax-up was completed, and since the restorative material was monolithic lithium disilicate, there is no need to complete a cutback on the digital wax pattern to allow for veneering porcelain. The amount of time required by the laboratory technician was minimal as the crown was digitally designed and sent to the manufacturer's milling center and returned in the pre-sintered state. Finishing the restoration involved fitting the crown to the abutment, verifying margination, staining and glazing, final cementation and final marginal polishing. With metal-ceramic implant crowns, a lab technician would have had to wax up the restoration to full contour, complete a cutback of the wax for veneering porcelain, invest the coping, cast the coping, layer porcelain, stain and glaze, and finish the restoration. While the list of steps for the metal-ceramic crown is not much longer that the CAD/CAM crown, the steps involved are very technique-sensitive and time consuming, not to mention the increase cost of material and metals.

The diameter of the screw access channel did not make a statistically significant difference in this study when comparing the difference in diameter amongst the samples. The most likely cause of the lack of significance is the difference among the diameter was held to as tight as tolerance as possible, and the variation in diameter wasn't that

great between samples. On the other hand, the screw access channel occupies a fair amount of the total occlusal surface. Hebel[10] reported the screw access through molars occupied more than 50% of the occlusal table and screw access through premolars occupied at least 50% of the occlusal table.[5]

Porcelain chipping was found to be significantly higher among screw-retained implant restorations, which can be explained by a weakening of the occlusal porcelain made by the screw access channel.[11] Wittneben's study tested porcelain-fused-to-metal crowns and the results may not apply to a modern monolithic material such as lithium disilicate.

A limitation of this study is that it was completed on a premolar-size tooth with the minimal acceptable amount of restorative material over the abutment. This was done by design as a "worse-case scenario", with an additional hypothesis that if a molar-sized tooth was selected for use of lithium disilicate on a stock abutment, the restoring lithium disilicate material would be very thick and may skew the data, allowing for false assumptions. Additional studies need to be completed to assess different thicknesses of restorative material, different sized tooth replacements and different types of restorative materials, including zirconia. If a larger tooth size were chosen, the screw access hole diameter would occupy less of the overall occlusal surface of the restoration, allowing for more sound and supported lithium disilicate. Testing could also be carried out in a chewing simulator instead of a pure vertical load machine, to evaluate a more real-world simulation and durability of the experimental specimen.

CHAPTER 6: CONCLUSIONS

This novel screw- and cement-retained combination for an implant restoration was the initial journey into the realm of combining the 2 treatment modalities in restoring implant by accentuating the positives of each and minimizing the negatives. While the data in this specific experiment proves this specific restoration is not substantial or durable enough for safe and effective patient use, the testing process and experimental design is in place to begin testing other restorative materials utilizing this novel approach.

Based on the results of this research, a premolar-size lithium disilicate restoration cemented extraorally on a stock abutment and delivered as a screw-retained implant restoration is not advised due to the decreased axial load to failure.

Different results may be obtained using a molar-size tooth with a larger bulk of lithium disilicate for the restoration or using a different restorative material, such as zirconia. More testing is indicated using different parameters and materials before a safe and effective implant restoration can be moved forward into clinical testing.

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