Effect of a screw-access channel on the fracture resistance of monolithic zirconia crowns

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Mitchell Loeb, D.D.S.

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Heather Joan Conrad, D.M.D., M.S
Faculty Advisor

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DEDICATION

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ABSTRACT

Purpose
This in-vitro study was designed from a clinical case and investigated the effect of the presence of a screw assess channel, created either during the milling phase or following cementation, on the fracture strength of a monolithic zirconia cement-retained implant-supported fixed prosthesis (ISFP).

Material & Methods
A definitive cast from a clinical case restoring a mandibular right first molar implant was utilized to fabricate three different styles of monolithic zirconia cement-retained ISFP. Group 1 had no screw-access channel **(CR)**, Group 2 had a screw-access channel milled in the green phase **(MA)**, and Group 3 had a screw-access channel created by hand preparation after cementation **(HA)**. With 3 groups and 5 samples in each group, there were a total of 15 monolithic zirconia crowns fabricated on custom abutments in preparation for testing. The maximum force required for crown fracture was measured using a universal testing machine.

Results
The mean loads to fracture from highest to lowest were: the milled screw-access channel group (MA), followed by the hand-made screw-access channel group (HA), and lastly by the cement-retained group without a screw-access channel (CR). One-way ANOVA analysis indicated the fracture strength of the MA was statistically significantly different than the cement-retained samples ($P<0.05$). No statistically significant differences were found between the milled screw-access channel and the access channel created by hand.

Conclusion
The presence of a screw-access channel, whether milled or prepared by hand, does not negatively affect the fracture strength of a monolithic zirconia ISFP.

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CHAPTER 1: INTRODUCTION

There are many key factors contributing to the success of implant restorative therapy, including an integrated implant and a prosthesis that provides esthetics and function.[1] In attempts to provide fixed restorative therapy for patients missing a tooth, generally two options are available: a tooth-supported fixed dental prosthesis (FDP) or an implant-supported fixed prosthesis (ISFP). The latter has shown favorable long-term success rates compared to the FDP option.[2]

Restoring a cement-retained ISFP provides favorable occlusion and esthetics for patients, as there is no screw access channel incorporated into the crown, with a common restorative option being a custom titanium abutment with a monolithic zirconia crown.[3] There is continuous coverage of the occlusal surface, negating the necessity for additional restorative material to fill the screw access channel.[3]

Common prosthetic challenges accompanying implant therapy include abutment screw loosening, abutment screw fracture, porcelain chipping, or crown fracture.[4] There are several options to help manage these prosthetic challenges if they arise, including the use of temporary cements on cement-retained crowns.[4] Though this may lead to more frequent crown dislodgement or decementation and additional time for the restorative dentist, the aforementioned benefits of using a cement-retained crown may still prevail for the restoring provider.[5]

As one of the most common restorative challenges in implant dentistry is screw loosening, it is often necessary to access the abutment screw to re-torque the abutment screw in place.[6,10] If the ISFP is cement-retained, access to the abutment screw would be accomplished by drilling through the crown to find the access channel.[6]

The aim of this study was to investigate the effect of a screw access channel on the fracture strength of a monolithic zirconia ISFP. The results of this study will assist clinicians in determining the application and recognizing the prognosis of a cement-retained monolithic zirconia crown with and without a screw access channel.

CHAPTER 2: LITERATURE REVIEW

1. IMPLANT-SUPPORTED FIXED PROSTHESES

Implants offer a great alternative for replacement of teeth in partially edentulous areas, previously only achievable with a FDP or a removable partial denture. From a fixed prosthodontic perspective, there are comparable survival rates between traditional FDP and ISFP.[7]

As the ever-growing need for implant restorations increases, careful consideration must go into the decision for selecting the restorative material, whether it is metal-ceramic, lithium disilicate, monolithic zirconia, or veneered zirconia. With monolithic zirconia crowns having the highest reported fracture load, fracture strength, and elastic modulus of the aforementioned restorations, it is becoming the clinicians' restoration of choice for ISFP.[8] An additional important consideration when planning for an ISFP is whether the crown will be cement-retained or screw-retained.[10]

While there continues to be advancement in ISFPs, there are associated mechanical and biological complications that may be different to those associated with tooth-borne prostheses. Mechanical complications include fracturing of the veneering material, loss of restoration in the access hole access hole restoration, abutment or screw loosening or fracture, and decementation. Biologic complications include peri-implantitis, soft tissue recession, and bone loss secondary to residual implant cement and soft tissue complications.[2] With the given complications, it is important for clinicians to navigate through cement- or screw-retained restorations for ISFP.[10]

2. CEMENT- VERSUS SCREW-RETAINED ISFP

Cement-retained and screw-retained restorations are two restorative design options when planning for an ISFP. There are a number of evaluations that should be done when deciding between the two options, including esthetics, occlusion, retrievability of the prosthesis, porcelain fracture resistance, or restorative space.[11,12]

If esthetics is the primary concern for a patient, cement-retained prostheses are often the most favorable, eliminating the need for a visible screw-access channel.[10] Fortunately, there can be compensation for non-ideal angulation of the implant with a custom abutment and cement-retained ISFP without the need to have a screw-access channel in the restoration.[11] Additionally, cement-retained prostheses do not require dental laboratories to mill or create a screw-access channel in the prosthesis and can minimize complications.[11] Esthetic concerns remain when evaluating the presence of the screw-access channel in anterior ISFP, but similar concerns apply when posterior mandibular implants have this channel through the occlusal surface.[12] Often, anatomical limitations prevent ideal implant exiting through the cingulum of an anterior tooth or the occlusal surface of a posterior tooth.[12] Fortunately, opaque composites have aided in masking the gray hue from the channel and can aid in esthetics.[13] Even with the resorption patterns of bone, implant placement must take full advantage of present bone, which leads to off-axis placement of implant.[14]

Occlusal stresses are another important factor when deciding between a screw-retained or cement-retained prosthesis. Some studies state that stress distribution along the implant are improved with a cement-retained prosthesis.[15] Under biomechanical stress evaluation, there is higher risk of screw loosening and fracture with screw-retained prostheses.[15] There are mechanical improvements with cement-retained prostheses, due to better passivity of fit and more control over occlusal table without the need for screw-access channel.[15,49] If a prosthesis fits non-passively, it can negatively affect the load transfer to the prosthesis-implant-bone complex.[15] With migration of microorganisms transferring through the gap between the implant and abutment, there can be additional bone loss.[15] Guichet[16] looked at evaluation of marginal discrepancy and passive fit of screw-retained and cement-retained fixed dental prostheses. With more passive fit of cement retained restorations, there was significantly less stress concentration around the implant.[15,49]

A screw access channel will typically be 3 mm in diameter on the occlusal table of a posterior ISFP, thus influencing the ability to establish an ideal occlusal contact. Establishing proper occlusion on a screw-retained ISFP often requires a contact on the composite resin sealing the screw-access channel. As the composite resin wears, the centric occlusal contact could be lost more easily than a contact developed on metal, porcelain, or zironia.[13]

One of the primary advantages of having a screw-retained ISFP is the ease of retrievability if ever there is an issue with screw loosening or screw fracture.[6] There may be several reasons indicating the need for retrieving an ISFP, including the need for periodic replacement of prosthetic components, aforementioned screw loosening or fracture, abutment fracture, or modification of the prosthesis following loss of an implant.[9]. The ease of removing of a screw-retained ISFP is already noted, but conversely, if a crown requires removal in a cement-retained ISFP, then the integrity of the prosthesis may be jeopardized after creating a screw access channel.[11]

One major drawback when considering cement retention is the challenge of removing excess cement. Any residual cement that remains on the surface of the abutment can lead to peri-implant mucositis and peri-implantitis, a local inflammatory disease resulting from bacterial colonization of the foreign material (cement). This process can progress even after several years following delivery of the ISFP.[17] A subgingival margin on a cement-retained ISFP is more likely to harbor residual cement in the sulcus.[18] While there is may be more ease of placement and decreased clinical time associated with a cement retained restoration compared to a screw-retained restoration, it is critical for clinicians to recognize that there are associated risks, especially with increased likelihood of excess residual cement.[19,20]

Additional complications can occur outside of screw loosening, including porcelain fracture, loss of retention, fracture of abutment, or fracture of screw.[4, 7,21] Not only is it important to properly select a screw-retained restoration or a cement-retained restoration for ISFP, but it is also critical to understand the different restorative materials available.[22,23]

3. FRACTURE STRENGTH OF DIFFERENT RESTORATION MATERIALS

One consideration when selecting the restorative material for an ISFP is fracture resistance or strength of the material. Popular choices have included metal, metal ceramic, zirconia, and lithium disilicate.[24]

Weyrauch[25] conducted a study to evaluate the fracture strength of different monolithic all-ceramic crowns on titanium implant abutments. Within this study, 525 crowns of seven different materials were evaluated as well as five different luting agents. Of the seven different materials that were evaluated, zirconia-reinforced lithium disilicate had the highest fracture strength, followed by lithium disilicate glass ceramic, resin nanoceramic, and then hybrid dental ceramic with polymer network.[25] Finely structured feldspathic ceramic, zirconia-reinforced lithium disilicate (Celtra), and leucite-reinforced glass ceramic, had significantly lower fracture strength compared to the four materials tested above.[25] One interesting finding from this article is that there was no significant difference with the different luting systems that were used, which included self-curing luting composite (Multilink Implant), dual-cured luting composite (Variolink II), self-adhesive resin cement (RelyX Unicem), resin-modified glass ionomer luting cement (GC Fujicem), and self-adhesive/self-etch dual-cure resin cement (Panavia). While this study looked strictly at cement-retained restorations on implants, it is clear that zirconia-reinforced lithium disilicate (Vita) had the highest fracture strength.[25]

Torrado[26] concluded that screw-retained metal-ceramic ISFPs demonstrated a significantly lower fracture resistance than cement-retained metal-ceramic ISFPs. Within this study, the purpose was to compare fracture strength of porcelain between screw-retained and cement-retained metal-ceramic implant ISFPs, and there was no significant difference found between porcelain fracture of the metal-ceramic ISFPS 4 mm or 5 mm width in occlusal tables in cement-retained groups.[26] They concluded that the screw access location did not have any effect on the porcelain fracture resistance, either positively or negatively.[26]

A third type of restoration that is commonly used for full contour restorations in dentistry is lithium disilicate.[27] When evaluating fracture resistance of lithium disilicate bonded to enamel or dentin, Rojpaibool[27] found that there were higher fracture loads noticed with thinner film thicknesses and higher fracture loads when the restoration was bonded to enamel.

Lithium disilicate ISFPs were also evaluated for their fracture resistance on titanium and zirconia implant abutments.[28] Within the limits of this study by Martinez-Rus[28], the highest fracture resistance without substructure fracture was seen with lithium disilicate ISFPs; however, the failure type was more favorable with titanium abutments and zirconia crowns because there was no fracture observed in the crown or the abutment. Instead, implant neck distortion was observed.[28]

4. FRACTURE AND FLEXURAL STRENGTH FOR MONOLITHIC ZIRCONIA

Saker[29] evaluated the fracture resistance in straight and angulated zirconia abutments supporting anterior three-unit lithium disilicate ISFP. Angulated zirconia abutments are being used to compensate for off-axis implant angulations and this study showed that this use is possible without reducing the load-bearing capacity of three-unit lithium disilicate ISFP.[29] Of these implant abutments, zirconia straight abutments had the highest mean fracture strength of 542.17 N, and the titanium angulated abutment had the lowest mean fracture strength of 523. 57 N.[29] Between the different abutment materials and angulations of implants, there was no significant difference in fracture strength.[29]

When the restorative space is limited, monolithic zirconia crowns are increasingly being considered as the restorative material for ISFP.[5] One question associated with the use of monolithic zirconia is what minimal thickness is acceptable, both for FDP and for ISFP. According to Lan[5], cyclic loading tests of ISFP revealed the fracture resistance of monolithic zirconia was positively associated with thickness noting that a minimum thickness of 0.8 mm is recommended to allow for deviation and allowable error in occlusal adjustment. Deng[29] added that monolithic zirconia had relatively high critical contact loads of 800 to 900 N when the thickness exceeded 0.7 mm.

When evaluating fracture strength intraorally, Sulaiman[3] used commercial laboratories and surveyed the fracture rate that translated to catastrophic failure of monolithic zirconia restorations up to five years. Of the 36,096 posterior monolithic zirconia restorations that were completed, 0.99% of all restorations failed due to fracture. While interesting to know the specific failure rate of monolithic zirconia across such a large sample, this survey only included restorations on natural teeth and excluded all implant restorations.[3]

As the thickness of zirconia increases, so too does the flexural strength.[30] Though Ozer[30] found the flexural strength of monolithic zirconia discs increased when thickness was increased, the material can withstand masticatory forces at both 0.8 mm and 1.3 mm thicknesses. Additionally, this study compared air-borne particle abrasion with grinding and polishing and found that air-borne particle abrasion increased the flexural strength but grinding and polishing had no effect.[30, 51]

Specifically relating to fracture strength of zirconia crowns on implant restorations, Nogueria[31] explored veneered zirconia ISFPs and their fracture strength when cement-retained or screw-retained on custom zirconia abutments. When the veneered zirconia crowns were cemented onto custom zirconia abutments, there was greater fracture resistance than the veneered zirconia crowns that were screw-retained.[31] Within this study, it was also found that cyclic fatigue of the specimens did not seem to influence the fracture resistance of these crowns, and the fracture of the veneering ceramic was predominant failure of the specimens.[31]

5. ABUTMENT SELECTION FOR IMPLANT RESTORATION

Generally, zirconia and titanium are the most common materials used for custom implant abutment.[28] Zirconia abutments are chosen because of their high strength; however, due to their opacity, it has been suggested that lithium disilicate abutments could be more esthetic than zirconia abutments and replace traditional titanium abutments.[29] Elsayed[32] concluded that metal inserts with lithium disilicate and zirconia abutments could have the potential to withstand the physiologic occlusal forces that occur in the anterior region and they can be recommended as an esthetic alternative for restoring implants in the anterior region.[32] Additionally, the fracture strength of lithium disilicate abutments was not affected when used as a combination of the overall crown or separate abutment and crown.[32] This study recommended the use of titanium inserts when using zirconia abutments, as there is a much higher fracture strength than pure zirconia abutments.[32]

Evaluating the fracture resistance of all-ceramic crowns (monolithic lithium disilicate, pressed lithium disilicate, and monolithic zirconia) on both zirconia and titanium abutments, Martinez-Rus[28] found titanium abutments had higher durability than zirconia abutments. With all three crowns, the higher durability equated to higher mean fracture resistance of all three crown types on the titanium abutments, compared to the same crown types on zirconia abutments.[28] Additionally, this was not a pure zirconia implant but was rather a zirconia abutment with a titanium connection and was evaluated for a right maxillary central incisor.[28]

Restoring implants with titanium abutments have a long and well-documented history; however, there can be a grayish appearance at the gingival margin when the tissue thickness is 2 mm or less.[33] Zirconia abutments are an alternative to titanium abutments and are popular for restoring anterior implants.[33]

While zirconia abutments are an option for restoring abutments within the esthetic zone, anodization or titanium nitride coating for titanium abutments are also options for disguising the greyish hue with titanium abutments.[31] The anodization process can produce desirable colors, such as yellow or pink to mask the color of the titanium alloy. This process is completed by connecting a positive electric probe to the titanium alloy and submerging it into an electrolytic solution, causing a thin layer that gives off different wavelengths of the visible light spectrum.[35,36] An alternative solution is titanium nitride (TiN) for titanium abutments, which tends to enhance titanium alloy with excellent resistance to corrosion, hardness, biological properties, and yellowish color. It can be prepared by nitrogen ion implantation, physical vapor deposition, and plasma ion nitriding.[34-37]

Because esthetic demands are lessened for posterior sites, particularly first or second molars, there is no contraindication, other than restorative space issues, for using a titanium abutment.[24,27] If there is limited restorative space, a castable abutment can be utilized to create a one-piece abutment-crown unit that is not dependent on cement.

6. ACCESSING ZIRCONIA CEMENT RETAINED CROWN

One common restorative complication of implant dentistry is the loosening of an abutment screw.[7] One of the largest disadvantages of cement-retained ISFPs is its challenging retrievability. Barbosha da Rocha[41] suggests a technique incorporating a cement retained crown with a screw-access channel. If a crown is cemented without a screw access channel, there are options for mapping the locations of the screw-access channel for future access, including a diagram in the patient's chart with the location of the screw-access channel or creation of a vacuuform matrix that seats over the restoration with the screw-access channel location.[10]

Grinding on zirconia affects phase transformation, flexural strength, microhardness, and subsurface damage depth.[44] Cutting pre-sintered zirconia in a dry environment had an increase in phase transformation, but the residual compressive stress formed under the ground surface enhanced the flexural strength of the dry ground surfaces.[44] Under wet conditions with pre-sintered zirconia, flexural strength was reduced.[44] Khayat[52], alternatively, concluded that grinding on zirconia had no significant effect on the flexural strength. Following sintering, grinding zirconia with medium rough diamond burs (75 μm or 54 μm) will introduce grinding damage that could have negative consequences on the mechanical behavior of zirconia.[45] It has been recommended to adjust zirconia with fine-grit diamond grain sizes (18 μm or below) to obtain chips limited in depth and non-critical to the material.[45] If cracks do penetrate further than the surface layer of the zirconia, then the overall flexure strength can be affected.[53]

7. FILLING MATERIAL WITHIN SCREW-ACCESS CHANNEL

Studies have evaluated presence or lack of composite resin for screw-retained crowns and effect of filing material on retentive force of cement-retained restorations.[47,48] Five different filling materials were examined, including composite resin (Filtek Z 250), light-cured temporary filling (Clip), temporary filling (Coltosol), polyvinyl siloxane (PVS), impression material (Elite H-D), and PTFE thread sealant tape.[47] When the screw access channels were filled with PVS or PTFE, the temporarily cemented ISFP were more easily removed.[47]

With screw-retained metal ceramic ISFP, unrestored screw-access channels found significantly more chipping fractures than restored screw-access channels.[47] Light-cured temporary filling and composite resin filling notably had higher retention with temporarily cemented cast ISFPs.[48] The presence of composite resin filling the screw access channel can stabilize the ceramic layer, which leads to less chipping of the veneering layer.[47]

SPECIFIC AIM

To measure and compare the fracture strength of a monolithic zirconia ISFP without a screw access channel, with a milled screw access channel, or with a screw-access channel created through a cement-retained crown.

STATEMENT OF THE PROBLEM

Various restorative design options for ISFP are available, including cement-retained, screw-retained, or cement-retained with a screw-access channel milled into the prosthesis. A common prosthetic complication with an ISFP is screw-loosening, thus requiring access to the abutment screw. No studies were found that compared the fracture strength of monolithic zirconia ISFP when designed as a cement-retained restoration, cement-retained restoration with a milled screw access channel, or cement-retained restoration with a screw-access channel created following cementation.

NULL HYPOTHESIS (H0)

The presence of a screw-access channel in a cement-retained ISFP created either during the milling phase or following cementation will not influence the fractural strength of a monolithic zirconia crown.

ALTERNATE HYPOTHESIS (H1)

The presence of a screw-access channel in a cement-retained ISFP created either during the milling phase or following cementation will influence the fracture strength of a monolithic zirconia crown.

CHAPTER 3: METHOD AND MATERIALS

Fifteen custom abutments (ATLANTIS abutment; Dentsply Sirona) designed for a 5.4 mm by 11 mm mandibular right first molar implant (OsseoSpeed EV; Dentsply Sirona) from a clinical case, were milled with the same parameters (Figs. 1 and 2). These 15 custom abutments were then divided into 3 testing groups based on the style of the ISFP. The ISFP styles and test groups were: a cement-retained crown without a screw-access channel **(CR)**, a cement-retained crown with a milled screw-access channel **(MA)**, and a cement-retained crown with an access channel created by hand preparation after cementation **(HA).**

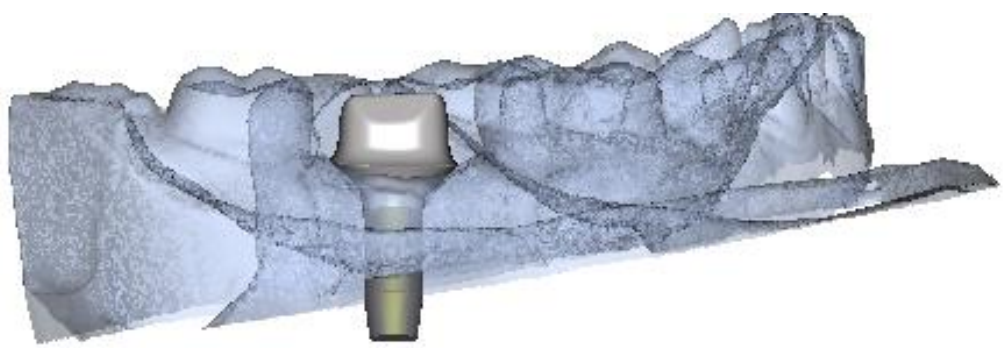


Figure 1. Custom abutment fabrication (buccal view)

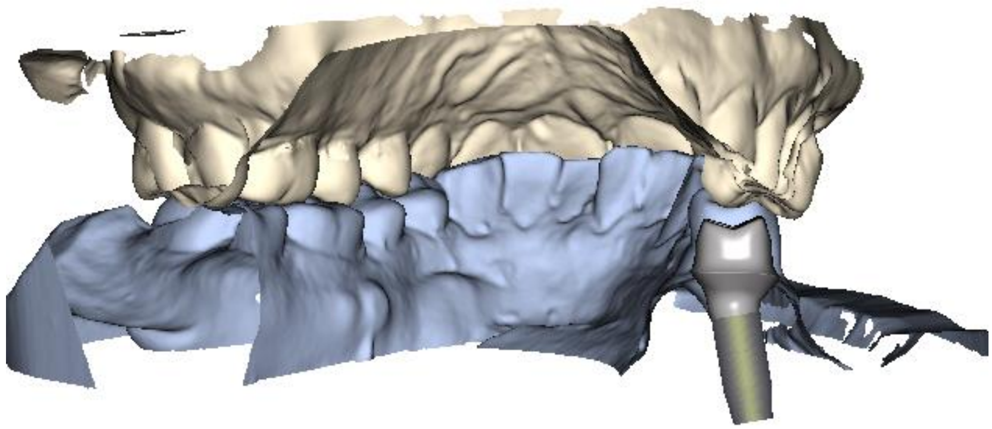


Figure 2. Custom Abutment Fabrication (posterior view)

The custom titanium abutment was then scanned with an optical scanner (3Shape; E2, Copenhagen, Denmark) and crowns were designed and fabricated. The default die spacer of the scanner was 30 µm. A total of 15 CAD/CAM monolithic zirconia crowns were milled. The shape and fit of each crown were evaluated on the master abutment. The zirconia was then sintered according to the manufacturer's instructions (The Argen Corporation; Argen ZT+, San Diego, CA). To aid in the creation of a screw-access channel following the cementation of the cement-retained crowns, the occlusal surfaces on the crowns in the HA group were stained approximately where the screw access channel was located.

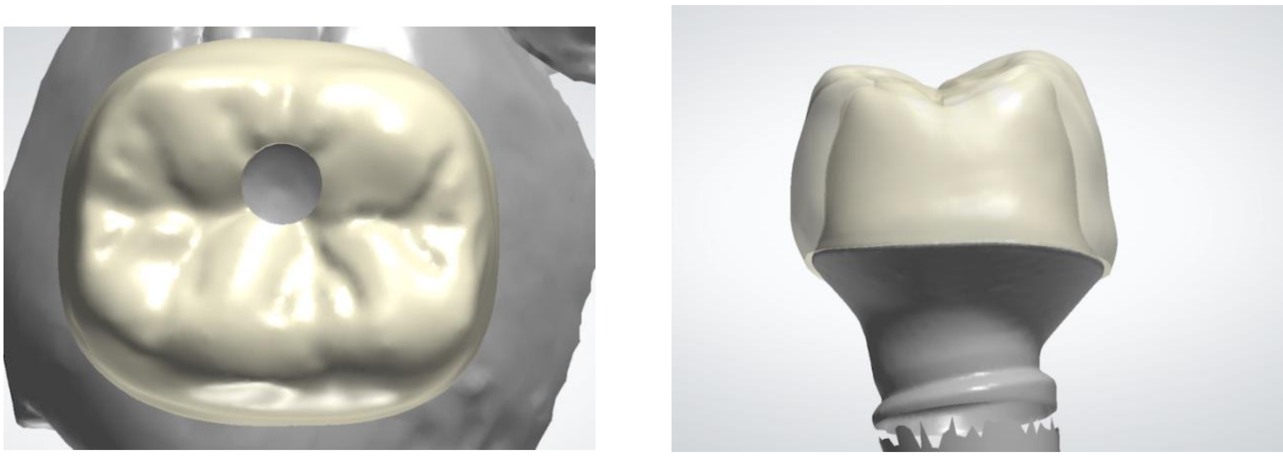


Figure 3. Scanning and design of monolithic zirconia crowns.

Figure 4. Lab benchtop scanner

The crowns were divided equally into three different groups (n=5). With 25 Ncm torque value, each of the 15 abutments were connected to the implant analog that was embedded in the clear orthodontic resin bath (Caulk Orthodontic Resin; Dentsply, Milford, DE). After 10 minutes, the abutment screw was re-torqued to the implant analog to compensate for a settling effect of the screw.[50] An inch-long piece of polytetrafluoroethylene (PTFE) thread sealant tape (Scienceware FLUO-KEM teflon tape) was cut and placed in to the screw access channel to protect the screw hex from excess cement flow into the screw joint.

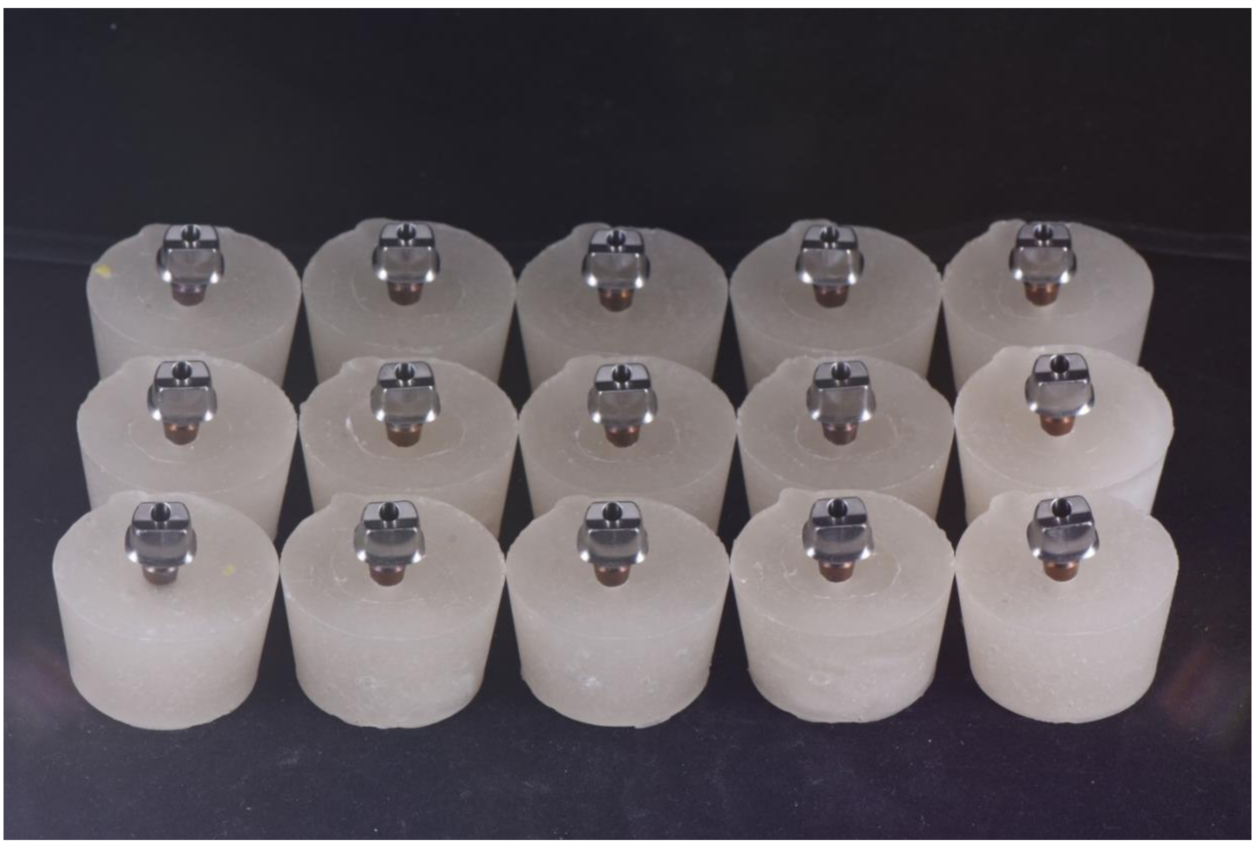


Figure 5. Milled custom abutments

The exterior surface of the implant abutments and intaglio surface of the crowns were airborne-particle abraded (50 μm Al_2O_3, approximately 2 cm distance, 0.15 MPa pressure, approximately 60-second airborne-particle abrasion time per abutment and crown) to increase the shear bond strength.[51] This was then followed by water steaming and ultrasonic cleaning in distilled water for 10 minutes.

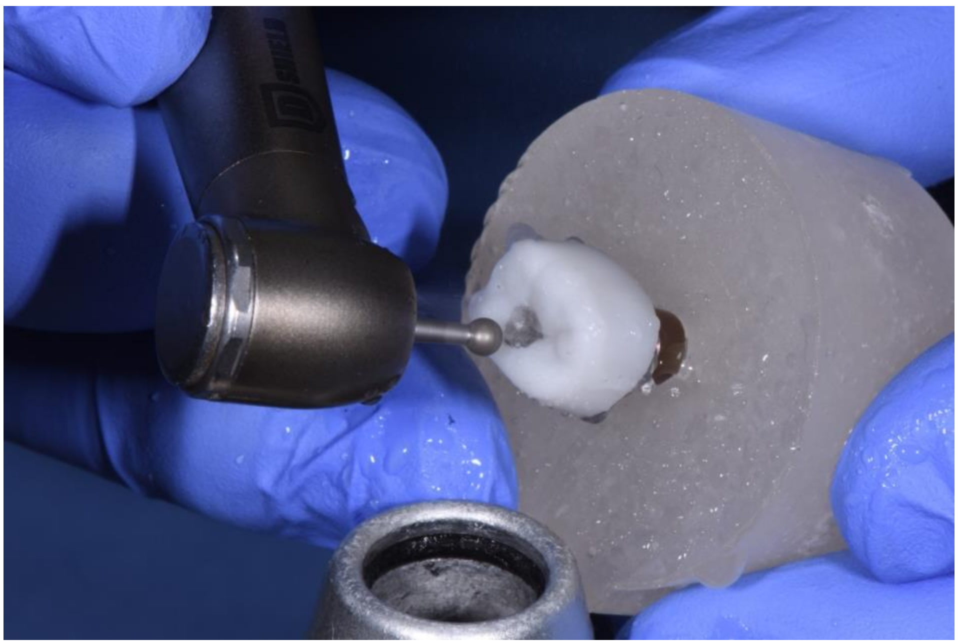


Figure 6. Creating access to abutment screw

Each group was cemented with self-adhesive resin cement (RelyX U200, 3M ESPE) on its corresponding abutment and excess cement was removed with a microbrush (Mircrobrush micro applicator) and then sickle scaler (Hu-Friedy Mfg Co LLC). For all three groups, the crowns were placed under a static load of 49 N for 10 minutes with a custom-made device applying load through a 6 mm spherical ball.

After cement polymerization, the cement-retained crowns with milled screw-access channels were reseated with the abutment screw through the screw access channel and tightened to 25 Ncm. The channel was then sealed with PTFE thread sealant tape (Scienceware FLUO-KEM teflon tape) followed by a composite resin plug (Filtek Z250 Universal Restorative; 3M ESPE).

To simulate accessing a cement-retained crown with a loose abutment screw, the five specimens in group HA were manually accessed by highspeed instrumentation to reach the PTFE thread sealant tape (Scienceware FLUO-KEM teflon tape). The PTFE thread sealant tape (Scienceware FLUO-KEM teflon tape) was then removed, and it was ensured the implant driver could adequately access the abutment screw. The abutment screw was then retorqued to 25 Ncm, then the new screw access channel was sealed with PTFE thread sealant tape (Scienceware FLUO-KEM teflon tape) followed by the aforementioned composite resin plug.

Figure 7. Handmade screw-access channel (left) vs. milled screw-access channel (right)

All specimens were stored in distilled water at 37°C for 24 hours prior to testing. Following this, the specimens were individually mounted to the lower head in a universal testing machine (MTS 858 Mini Bionix II). Specimens were individually numbered and randomly ordered using spreadsheet software (Excel; Microsoft Office). The axial load was applied with a 5.8 mm diameter metallic sphere with a spacer between the sphere and specimen, loading at a 0.5 mm/min speed. The axial load was recorded against time, and the data of the maximum axial load was collected for each of the specimens, equating to the failure load.

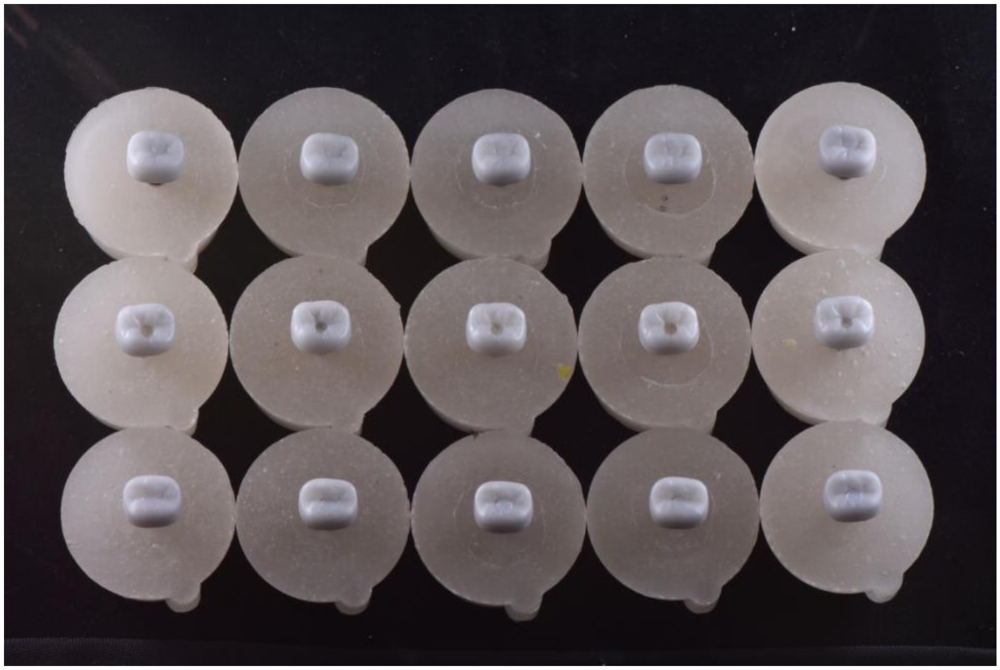


Figure 8. Cement-retained (CR), milled screw-access (MA), and handmade screw-access (HA) Groups

For the statistical analysis, a spreadsheet (Excel; Microsoft Office) was created with the data from the three test groups. 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. To find out which groups were different, pair-wise comparisons were conducted and adjusted for multiple comparisons. A *P*-value of <0.05 was considered significant.

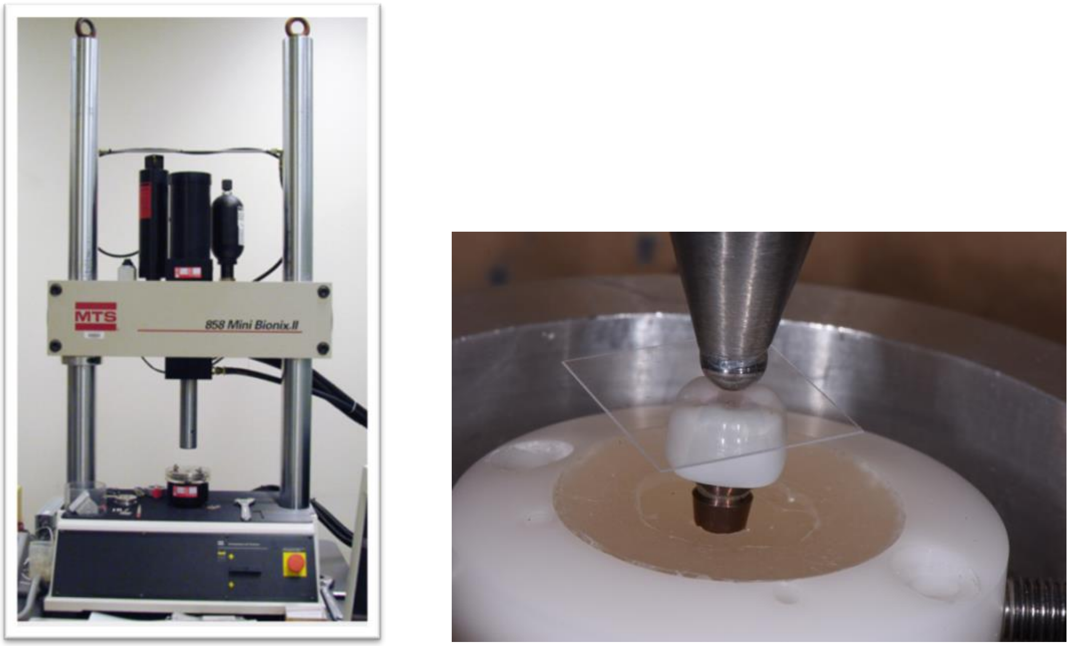


Figure 9. Testing machine a) Universal testing machine (MTS 858 Mini Bionix II)

b) Close-up of sphere and specimen on testing machine

Figure 10. Example of fracture failure of (a) CR, (b) MA, and (c) HA specimens

CHAPTER 4: RESULTS

The null hypothesis stated that the presence of a screw-access channel in a cement-retained ISFP created either during the milling phase or following cementation will not influence the fractural strength of a monolithic zirconia crown. The primary analysis involved three different groups with five samples in each group for a total of 15 monolithic zirconia crowns. The mean, median, minimum, and maximum load required to fracture the full contour crowns with different designs are presented in Table 1 and Figure 11**.**

Overall, *P*-value of one-way ANOVA statistic was calculated ($P<0.05$), comparing the means between two or more groups. The *P*-value (Pr(>F)) is less than 0.05 and indicates that at least two groups differ significantly.

As the ANOVA indicates that at least two means differ, pairwise comparisons were conducted with Tukey-Kramer method for multiple comparison adjustment. The tests indicate that the samples with the milled screw-access channel differ significantly from the samples without any screw access channel (cement-retained); however, the group with the screw-access channel created by hand preparation after cementation did not differ from either the cement-retained samples or the samples that had the milled screw-access channel. With a *P*-value of 0.0952, the comparison of the milled screw-access channel with the screw-access channel created by hand preparation may have a significant difference with a larger sample size.

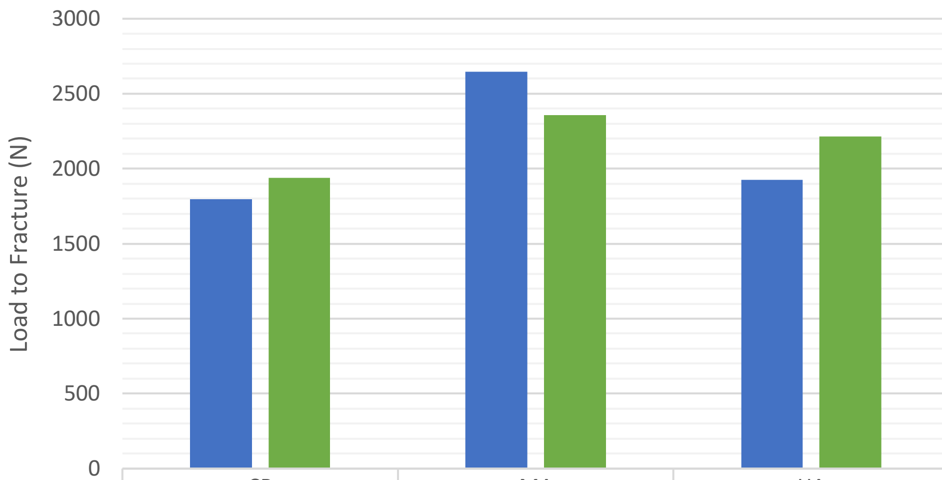
Table 1. Mean and Median value (N) of each test group

Test Groups	Category			
	N	**Median**	**Mean (SD)**	**(Min, Max)**
CR	5	1938.02	1797.39 (343.64)	(1252.85, 2072.63)
MA	5	2355.46	2647.90 (482.90)	(2283.62, 3386.58)
HA	5	2214.64	1924.56 (627.12)	(1222.97, 2599.52)

The milled screw-access channel group had the highest mean load to fracture, followed by the hand preparation screw-access channel samples, followed lastly by the cement-retained samples (Table 1).

Table 2. Statistical comparison among test groups

GROUP 1	GROUP 2	Estimate	Standard Error	Adjusted *P*-value
MA	**CR**	850.5	315.1	0.0474*
HA	**CR**	127.2	315.1	0.9147
HA	**MA**	-723.3	315.1	0.0949



	CR	MA	HA
Mean	1797.39	2647.9	1924.56
Median	1938.02	2355.46	2214.64

Figure 11. Mean and median value (N) of each test group

The presence of an access channel led to a higher mean fracture strength when the access channel was milled as compared to the access channel samples that were created by hand preparation. The control group with no access channel (cement-retained) showed the lowest mean value.

CHAPTER 5: DISCUSSION

The data partially support the acceptance of the null hypothesis; that there is no difference among CR, MA, and HA groups. While the group with the screw-access channel created by hand preparation after cementation did not differ statistically from either the control group or the milled screw access, the milled screw access channel samples differed statistically from the cement-retained samples.

Though the crowns in the HA group had staining on the occlusion surface to mark the anticipated screw-access channel to facilitate preparing an ideal access opening, there is concern that drilling through a cement-retained ISFP will damage the prosthesis irreparably. Within the present study, the milled access channel and handmade access channel actually had higher mean fracture strengths than the prosthesis that had no access channel, indicating the strength of the crown was not affected by drilling through the occlusal surface either before or after cementation to the custom titanium abutment. This agrees in part with Khayat[52], which concluded that grinding on zirconia had no significant effect on the flexural strength.

The advantage of having a screw retained prosthesis[20,21,22] is to aid in the accessibility of retrieving the abutment screw when complications arise. One of the most common technical complications with implant restorations is screw-loosening, which necessitates the screw needing to be replaced or retightened.

When it is necessary to access a cement-retained crown for any of the aforementioned complications, the access channel must be found by drilling through the crown. This investigation was to compare the fracture strength of monolithic zirconia cement-retained without screw-access channel, cement-retained with milled screw-access channel, and cement-retained crowns with screw-access channels created by hand preparation.

Though this study had two cracks noted while creating hand access to the cement-retained crowns (Figure 12), the overall fracture strength was not significantly different compared to the other two samples. If cracks propagate further than through the surface layer of zirconia, then the flexural strength can be lowered.[53] Within the present study, the surface defects only affected the superficial layer of the material and did not have significant deterioration of the mechanical properties of the material.

No previous studies were found that reported the fracture strength of different monolithic zirconia ISFP on titanium custom abutments. The data from the three sample groups reported slightly higher fracture strength of monolithic zirconia than Hussien[6] which reported fatigue failure load of three different types of ceramic ISFP. The three crowns evaluated were lithium disilicate, veneered zirconia, and monolithic zirconia, with and without milled screw access channels. Differing from the present study, though, there were no access channels simulating the handmade access to the channel.

Within this study, both the cement-retained crown with milled screw-access channel (MA) and the access channel created by hand (HA) did not have lower fracture strengths than the cement retained crowns with no access channel, similar to Hussien[6]. Many studies have evaluated the fracture strength of ISFP with presence or absence of a screw access channel, and many have found strength is not lowered with presence of a screw-access channel.[6, 25, 32, 33]

It is worth noting the torque was evaluated for all of the specimens following the testing, and none of the specimens appeared to retorque or lessen from 25 Ncm. This indicates the failure load of each of the specimens was not due to a mechanical failure or failure of the implant components underlying the monolithic zirconia crowns.

Interestingly, the mean fracture strength of the control specimens, with no screw-access channel present, was the lowest compared to the milled screw-access channel group and handmade screw-access channel group. One hypothesis for this is due to the unsupported zirconia in the cement-retained crown (CR**)** that lies on top of the access channel and PTFE thread sealant tape. Other studies have evaluated presence or lack of composite resin for screw-retained crowns and effect of filing material on retentive force of cement-retained restorations.[47,48]

With screw-retained metal ceramic ISFP, unrestored screw-access channels found significantly more chipping fractures than restored screw-access channels. The presence of composite resin filling the screw access channel can stabilize the ceramic layer, which leads to less chipping of the veneering layer.[47]

Retention has been evaluated with various screw access channel fillings on cement-retained crowns that are cemented using temporary cement. Five different filling materials were examined, including composite resin (Filtek Z 250), light-cured temporary filling (Clip), temporary filling (Coltosol), polyvinyl siloxane (PVS), impression material (Elite H-D), and PTFE thread sealant tape. When the screw access channels were filled with PVS or PTFE, the temporarily cemented ISFP were more easily removed. Light-cured temporary filling and composite resin filling notably had higher retention with these temporarily cemented cast ISFPs.[48]

Though these previous studies evaluated presence of composite resin on screw-retained ISFP and filling material for the screw-access channel on cast ISFP, there were no studies found that examined the presence or lack of composite resin filling for a cement-retained zirconia ISFP. Within the current study, the only filling material covering the screw-access channel was PTFE thread sealant tape without composite resin. Further studies would be needed to evaluate whether the fracture strength is affected with composite covering the screw-access channel for a cement-retained monolithic zirconia ISFP.

Another source of error could be introduced from non-standardized computer-aided design and computer-aided milling of both the abutments and crowns. If there were any inaccuracies or non-standardization on the manufacturing of the duplication of crowns or abutments, then this could have altered the results of this study or caused error or even lead to decreased passivity of fit of the prosthesis. While cement-retained implant superstructures have the potential of being passive, there is always possibility of error accumulating in each step of fabrication that leads to pure passivity being extremely rare.[49]

While milling the abutments or crowns, it is impossible to know whether the milling burs possess the same sharpness or milling efficiency. In the same turn, while the same fine diamond round bur (Brasseler, Brasseler USA, Savannah GA) was used to make the handmade access within the five samples, it is possible the bur dulled near the end of preparing these samples.

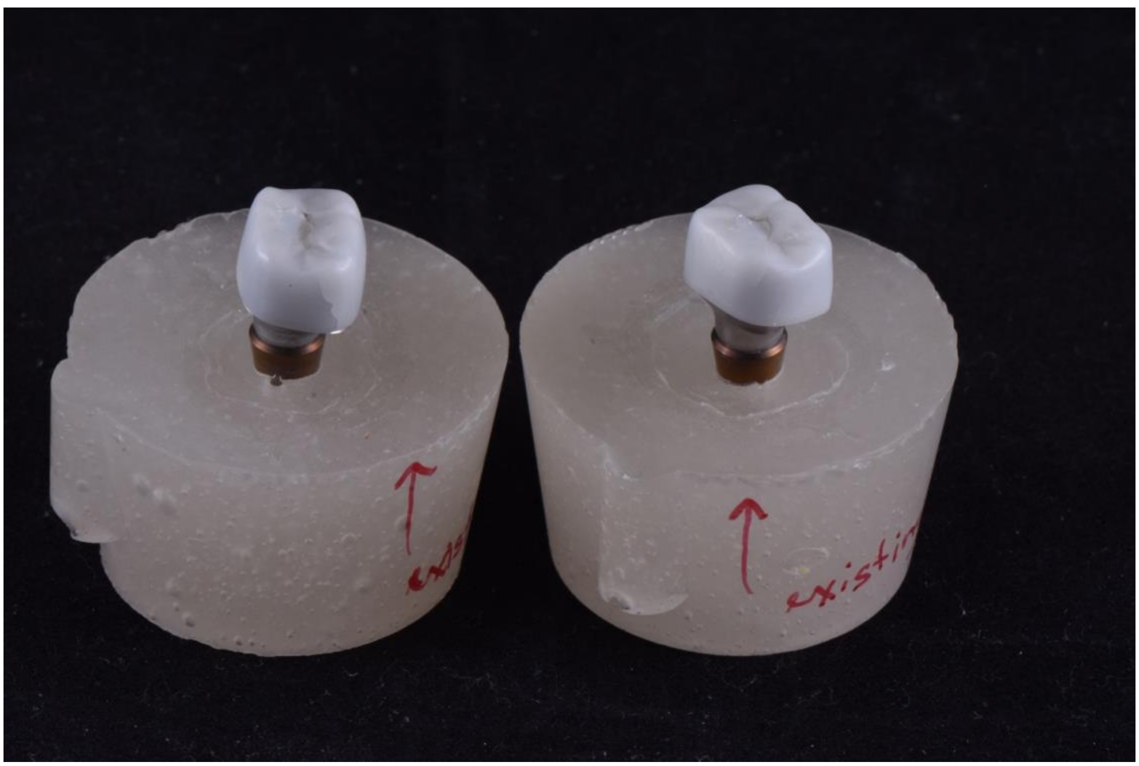


Figure 12. Crack following handmade preparation of screw-access channel

Limitations to the current study include small sample size and lack of simulating the oral environment. While this study did reproduce the oral environment by having the samples stored in 100% humidity at 37°C for 24 hours, there was not cyclic loading or cyclic fatigue of the samples prior to testing.

Future studies need to be performed with larger samples within each group, especially as there could have been statistical significance between the milled screw-access channel and handmade screw-access channel if a larger sample size was chosen. Additionally, to build upon the findings of this study, a fourth sample group with a composite plug over the access channel in the cement-retained or control group could have made the finding more clinically relevant and determination of whether composite addition could strengthen the overall ISFP.

CHAPTER 6: SUMMARY AND CONCLUSION

This study was conducted to determine whether accessing a crown after cementation affected the fracture strength of monolithic zirconia ISFP. The null hypothesis was partially rejected. Based on the limitation of this study, the following conclusions may be drawn:

1. The presence of a milled screw-access channel or screw-access channel prepared by hand after cementation did not lower the fracture strength of a monolithic zirconia ISFP.
2. The milled screw-access channel group had the highest mean load to fracture, followed by the group with the screw-access channels created by hand preparation.
3. The fracture strength of the milled screw-access channel group is statistically higher than the group without a screw access channel (cement-retained).
4. The cement-retained group had the lowest mean load to fracture.

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. Sulaiman, T. A., Abdulmajeed, A. A., Donovan, T. E., Cooper, L. F., & Walter, R. Fracture rate of monolithic zirconia restorations up to 5 years: A dental laboratory survey. Journal of Prosthetic Dentistry 2016; 116(3), 436–439.
4. 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.
5. Lan, T. H., Liu, P. H., Chou, M. M. C., & Lee, H. E. Fracture resistance of monolithic zirconia crowns with different occlusal thicknesses in implant prostheses. Journal of Prosthetic Dentistry 2016; 115(1), 76–83.
6. Hussien, A. N. M., Rayyan, M. M., Sayed, N. M., Segaan, L. G., Goodacre, C. J., & Kattadiyil, M. T. Effect of screw-access channels on the fracture resistance of 3 types of ceramic implant-supported crowns. Journal of Prosthetic Dentistry 2012; 214–220.

7. Pjetursson, B. E., Thoma, D., Jung, R., Zwahlen, M., & Zembic, A. A systematic review of the survival and complication rates of implant-supported fixed dental prostheses (FDPs) after a mean observation period of at least 5 years. Clinical Oral Implants Research 2012; 23(SUPPL.6), 22–38.
8. De Kok, P., Kleverlaan, C. J., De Jager, N., Kuijs, R., & Feilzer, A. J. Mechanical performance of implant-supported posterior crowns. Journal of Prosthetic Dentistry 2015; 114(1), 59–66.
9. Chiche, G., & Pinault, A. Considerations for Fabrication of Implant- Supported Posterior Restorations. International Journal of Prosthdontics 1991; c; 37-44.
10. Hebel, K. S., & Gajjar, R. C. Cement-retained versus screw-retained implant restorations: Achieving optimal occlusion and esthetics in implant dentistry. Journal of Prosthetic Dentistry 1997; 77(1), 28–35.
11. Lemos, C. A. A., De Souza Batista, V. E., Almeida, D. A. D. F., Santiago Júnior, J. F., Verri, F. R., & Pellizzer, E. P. (2016). Evaluation of cement-retained versus screw-retained implant-supported restorations for marginal bone loss A systematic review and meta-analysis. Journal of Prosthetic Dentistry 2016; 115(4), 419–427.
12. Crespi, R., Capparè, P., Gastaldi, G., & Gherlone, E. F. Immediate occlusal loading of full-arch rehabilitations: screw-retained versus cement-retained prosthesis. An 8-year clinical evaluation. The International Journal of Oral & Maxillofacial Implants 2014; 29(6), 1406–11.

13. Michalakis, K. X., Hirayama, H., Pavlos, /, & Garefis, D. Cement-Retained Versus Screw-Retained Implant Restorations: A Critical Review. The International Journal of Oral & Maxillofacial Implants 2003; 719.
14. Chee, W. W., Torbati, a, & Albouy, J. P. Retrievable cemented implant restorations. Journal of Prosthodontics 1998; 7(2), 120–5.
15. Pimentel, A. C., Manzi, M. R., Polo, C. I., Sendyk, C. L., da Graça Naclério-Homem, M., & Sendyk, W. R. Photoelastic Analysis on Different Retention Methods of Implant-Supported Prosthesis. Journal of Oral Implantology 2015; 41(3), 258–263.
16. Guichet, D. L., Caputo, A. A., Choi, H., & Sorensen, J. A. Passivity of Fit and Marginal Opening in Fixed Partial Denture Designs. International Journal of Oral & Maxillofacial Implants 2000; 15, 239–246.
17. Wadhwani, C., & Chung, K. H. Limiting the dimension of a screw-access hole with an interim screw-retained prosthesis. Journal of Prosthetic Dentistry 2015; 113(6), 648–650.
18. Linkevicius, T., Vindasiute, E., Puisys, A., & Peciuliene, V. The influence of margin location on the amount of undetected cement excess after delivery of cement-retained implant restorations. Clinical Oral Implants Research 2011; 22(12), 1379–1384.
19. Pauletto, N., Lahiffe, B., & Walton, J. Complications associated with excess cement around crowns on osseointegrated implants: a clinical report. The International Journal of Oral & Maxillofacial Implants 1999; 14(6), 865–868.

20. Pjetursson, B. E., Brägger, U., Lang, N. P., & Zwahlen, M. Comparison of survival and complication rates of tooth-supported fixed dental prostheses (FDPs) and implant-supported FDPs and single crowns (SCs). Clinical Oral Implants Research 2007; 18(SUPPL. 3), 97–113

21. 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.

22. 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.

23. 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.

24. Nissan, J., Narobai, D., Gross, O., Ghelfan, O., & Chaushu, G. Long-term outcome of cemented versus screw-retained implant-supported partial restorations. Int J Oral Maxillofac Implants 2011; 26(5), 1102–1107.

25. Weyhrauch M, Igiel C, Scheller et al. Fracture strength of monolithic all-ceramic crowns on titanium implant abutments. Int J Oral Maxillofac Implants 2016; 31; 304-309.

26. Torrado, E., Ercoli, C., Mardini, M. Al, Graser, G. N., Tallents, R. H., & Cordaro, L. A comparison of the porcelain fracture resistance of screw-retained and cement-retained implant-supported metal-ceramic crowns. Journal of Prosthetic Dentistry 2004; 91(6), 532–537.

27. Rojpaibool, T., & Leevailoj, C. Fracture Resistance of Lithium Disilicate Ceramics Bonded to Enamel or Dentin Using Different Resin Cement Types and Film Thicknesses. Journal of Prosthodontics 2017; 26(2), 141–149.

28. Martínez-Rus, F., Ferreiroa, A., Özcan, M., Bartolomé, J. F., & Pradíes, G. Fracture resistance of crowns cemented on titanium and zirconia implant abutments: a comparison of monolithic versus manually veneered all-ceramic systems. The International Journal of Oral & Maxillofacial Implants 2012; 27(6), 1448–55.

29. Saker, S., El-Shahat, S., & Ghazy, M. Fracture Resistance of Straight and Angulated Zirconia Implant Abutments Supporting Anterior Three-Unit Lithium Disilicate Fixed Dental Prostheses. The International Journal of Oral & Maxillofacial Implants 2016; 31(6), 1240–1246.

30. Deng, Y., Lawn, B. R. and Lloyd, I. K., Characterization of damage modes in dental ceramic bilayer structures. J. Biomed. Mater. Res. 2002; 63: 137-145.

31. Ozer, F., Naden, A., Turp, V., Mante, F., Sen, D., & Blatz, M. B. Effect of thickness and surface modifications on flexural strength of monolithic zirconia. Journal of Prosthetic Dentistry 2018; 119(6), 987–993.

32. Nogueira, L. B. L. V., Moura, C. D. V. S., Francischone, C. E., Valente, V. S., Alencar, S. M. M., Moura, W. L., & Soares Martins, G. A. Fracture Strength of Implant-Supported Ceramic Crowns with Customized Zirconia Abutments: Screw Retained vs. Cement Retained. Journal of Prosthodontics 2016; 25(1), 49–53.

33. Elsayed, A., Wille, S., Al-Akhali, M., & Kern, M. Comparison of fracture strength and failure mode of different ceramic implant abutments. Journal of Prosthetic Dentistry 2017; 117(4), 499–506.

34. Jung RE, Sailer I, Hämmerle CH, Attin T, Schmidlin P. In vitro color changes of soft tissues caused by restorative materials. Int J Periodontics Restorative Dent 2007; 27:251-7.

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

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

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

38. 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.

39. 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.

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

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

42. Barbosa da Rocha, Aguiar Freitas, Alves da Cunha. Influence of screw access on the retention of cement-retained implant prostheses. Journal of Prosthodontics 2013; 109; 263-268.

43. Dahiya A, Baba N, Kattadiyil M, Goodacre C, Mann A. Comparison of the effects of cement removal from zirconia and titanium abutments: An in vitro study. J Prosthet Dent. 2019; 121; 504-509

44. Anand P, Arunachalam N, Vijayaraghavan. Effect of grinding on substructure modification of pre-sintered zirconia under different cooling and lubrication conditions. Journal of the Mechanical Behavior of Biomedical Materials 2018, 86; 122-130

45. Canneto, J.J. Cattani-Lorente, M, Durual, S., Wiskott, A.H., Scherrer, S.S. Grinding damage assessment on four high-strength ceramics. Dent. Mater 2016; 32, 171-182

46. Bover-Ramos, F., Viña-Almunia, J., Cervera-Ballester, J., Peñarrocha-Diago, M., & García-Mira, B. (2017). Accuracy of Implant Placement with Computer-Guided Surgery: A Systematic Review and Meta-Analysis Comparing Cadaver, Clinical, and In Vitro Studies. The International Journal of Oral & Maxillofacial Implants (2017), 1–15.

47. M., K., F., G., M.G., W., & S.M., H. The effect of load cycling on metal ceramic screw-retained implant restorations with unrestored and restored screw access holes. Journal of Prosthetic Dentistry 2008; 99(1), 19–24

48. Cakan, U., Gultekin, P., Guncu, M. B., & Canay, S. Effect of screw access channel filling materials on uniaxial retentive force of cement-retained implant restorations. Australian Dental Journal 2014, 59(1), 65–69.

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

50. Winkler, S., Ring, K., Ring, J. D., & Boberick, K. G. Implant Screw Mechanisms and the Settling Effect: An Overview. Overview of Implant Screws 2003;5:242–244.

51. Moon, J., Kim, S., Lee, J. Jung-Suk, H., In-Sung, Y., Seung-Ryong, H. Effects of airborne-particle abrasion protocol choice on the surface characteristics of monolithic zirconia materials and the shear bond strength of resin cement. Ceramics International 2006; 42:1552-1562.

52. Khayat, W., Chebib, N., Finkelman, M., Khayat, S., & Ali, A. (2018). Effect of grinding and polishing on roughness and strength of zirconia. Journal of Prosthetic Dentistry 2018; 119: 626–631.

53. Pereira GK. Amaral M, Simoneti, R. Rocha GC, Cesar PF, Valadro LF. Effect of grinding with diamond-disk and -bur on the mechanical behavior of a Y-TZP ceramic. J Mech Behav Biomed Mater 2014; 37:133-40

APPENDIX

Table 3. Raw Data

Control Group (No Screw-Access Channel)	
Sample	Failure Load (N)
1	1671.97
4	1938.02
7	1252.85
10	2051.48
13	2072.63
Group 1 (Milled Screw-Access Channel)	
Sample	Failure Load (N)
2	2283.63
5	2319.21
8	2355.46
11	3386.58
14	2894.60
Group 2 (Drilled Screw-Access Channel)	
Sample	Failure Load (N)
3	1222.97
6	1289.61
9	2599.52
12	2214.64
15	2296.04