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Title of Thesis: **The effect of occlusal forces on various zirconia restoration screw channel angulations cemented to a Ti Base**

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Title: The effect of occlusal forces on various zirconia restoration screw channel angulations cemented to a Ti Base.

Running Title: Effect of screw channel angulations on Ti base restorations.

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ABSTRACT:

Purpose: The purpose of this study is to test the load to failure on varying screw channel angulations in zirconia crowns cemented to a Ti Base abutment. It will investigate the effect of forces on the crown produced from differing screw channel angulations. Four different angulations will be tested.

Materials and Method: Forty implant replicas were placed in a custom titanium bar and zirconia Ti Base maxillary central incisor crowns of varying screw channel angulations were torqued to 20Ncm. The samples were placed in a universal testing machine at 135 degrees to the crosshead. A crosshead speed of 2mm/min was used to test load to failure of the varying screw channel angulation crowns.

Results: The load to failure fracture values of the 0-, 10-, 15-, and 20-degree screw channel angulations were 309.38N, 407.74N, 341.05N, and 338.04N respectively. Statistical significance was found between the 10-degree group and the 0- and 15- degree groups.

Conclusions: Within the limitations of this study, zirconia Ti Base crowns with 10-degree screw channel angulation have the highest fracture resistance compared to 0-, 15-, and 20-degrees.

INTRODUCTION

According to an estimate by the American College of Prosthodontists, one third of Americans, approximately 120 million people, are missing at least one tooth.¹ Regardless of whether a tooth is lost by trauma, periodontal disease, or dental caries, the goals of tooth replacement remain the same: restore the edentulous site. Not all edentulous sites are created equal, however, as location in the arch plays a pivotal role in the treatment planning process. Higher occlusal forces are the primary consideration for posterior sites, whereas esthetics and phonetics are the primary consideration for anterior ones.

Anterior implant restorations do not require the preparation of adjacent teeth for crowns², are not removable which patients generally desire, and are easily accessible for routine hygiene measures. Implant treatment, especially for the single missing anterior tooth with unrestored adjacent teeth, is a desirable option for both providers and patients alike due to its high esthetic potential and its high level of success³. Despite the advantages that dental implants provide, there are still treatment planning concerns that must be addressed prior to initiating treatment.

One consideration is whether implants are to be restored with cement-retained or screw-retained restorations. Cement-retained restorations are favorable when the implant angulation requires correction with the prosthesis and can be more esthetic by not having a screw access emerging through the crown. Custom titanium abutments have long been utilized to support single-tooth implant restorations, exhibiting favorable strength and excellent biocompatibility with surrounding gingival tissues. One disadvantage of titanium as an abutment, however, is the greying of the marginal gingival adjacent to the restoration. This causes an unaesthetic discoloration of the tissue which some patients and clinicians may dislike. Implant manufacturers created zirconia implant abutments to counteract this problem²⁴⁻²⁶. Zirconia implant abutments allow for better esthetics, but can have complications like wear and fracture at the implant-abutment interface²⁷. The success of titanium at the implant-abutment interface is

superior to zirconia due to its surface compatibility and adaptation. Baldassarri et al. supported this notion when he found that the mean gap between the titanium implant platform and the zirconia abutment is three to seven times greater than a titanium abutment²⁸.

A second disadvantage is that these restorations are at risk of cement retention in the peri-implant tissues which can cause periimplantitis, which can lead to implant loss. In 2009, Wilson et al noted that excess dental cement was associated with signs of peri-implant disease in 81% of the cases⁴. Screw-retained restorations are favorable when the implant can be placed to allow the screw channel to exit more palatal to the incisal edge, which allows for an esthetic restoration. Additionally, the absence of cementation and retrievability are beneficial to the peri-implant tissues and allow for easier prosthesis removal, respectively. The limitation of screw-retained restorations in the anterior maxilla is mainly esthetic in nature. If the implant is placed in the anatomic root position of a maxillary incisor, the screw channel will exit at the incisal edge or potentially out the facial aspect of the restoration approximately 83% of the time.⁵ This can lead to restorative failure due to esthetic compromises.

Angulated screw channel abutments have been recently introduced to address this problem. Nobel Biocare released the angulated screw channel (ASC) system which compromises a Nobel Procera crown utilizing the ASC solution. This is a one-piece restoration that can have up to 25 degrees of angulation from the implant platform to the screw channel opening. This allows for a lingual screw access channel instead of an incisal or facial channel. Limitations of this system are the requirement to use a proprietary monolithic zirconia restoration (Nobel Procera), a short abutment interface that relies on the abutment screw to retain the crown on the abutment, and the inability to fabricate in-office restorations. While zirconia may be a more esthetic abutment option than titanium, the brittle nature of zirconia can potentially lead to fractures of the abutment.⁶ In 2012, Baldassarri et al. found the mean gap between titanium implant platforms and zirconia abutments were three to seven times higher than titanium abutments.⁷

An alternative to the ASC are third-party titanium bases (ti-base) that incorporate a lingual access to the abutment screw at different angulations, utilizing unique drivers and abutment screws to allow proper torquing to a specified preload. An esthetic restoration is cemented onto the ti-base abutment, allowing for a completely titanium implant-restoration interface, while also providing an esthetic restoration due to restorative ability to make the emergence profile completely in ceramic. As such, there are a variety of restoration designs and materials, making this an excellent option for providers. One example an angulated to-base is the S-link Ti base (MIST Dental, Chantilly, VA). This prefabricated titanium base (Ti base) allows for up to 20 degrees of angulation while maintaining the titanium abutment-platform junction. Another benefit to the S-link Ti base is the ability to download their CAD libraries and use them in different CAD/CAM software applications. This gives the clinician or technician the option of fabricating restorations in-office instead of utilizing a proprietary dental laboratory. MIST uses their Torx® driver concept to allow for 20 degree angulation with full recommended torque delivered to the abutment screw⁸.

Clinicians use various dental ceramics to replace missing anterior teeth. Dental ceramics are an ideal material due to their esthetics, biocompatibility, and strength. The main categories of dental ceramics are: predominantly glass, particle-filled glass, and polycrystalline⁹. There are advantages and disadvantages to each category, however, clinicians are turning to zirconia as the material of choice for dental restorations due to the increased demand of metal-free restorations that imitate natural tooth structure.¹⁰ Furthermore, zirconia has numerous desirable mechanical properties with its flexural strength in the range from 900 to over 1200 MPa, a fracture toughness of 9-10 MPa.m^{10,11}, and a compressive strength of nearly 2000 MPa.¹²⁻¹⁴

3Y-TZP (3 mol% yttria) is considered the first generation of commercial dental zirconia^{15,16}. This zirconia has excellent mechanical properties with flexural strength values ranging from 900-1200 MPa, but is highly opacous and not esthetic by nature. It is more suitable as a substructure or core for porcelain fused to zirconia restorations. 4Y-TZP and 5Y-

TZP are the next generations of monolithic zirconia, in which more transparent phases were introduced to lower the opacity of the material. The increased translucency was achieved by adding higher yttria content with increased amounts of cubic phase. Because of this increased translucency, full-contour crowns are possible within addition of veneering porcelain for esthetics. Despite their esthetic potential, the increase in translucency and esthetics additionally causes a decrease in strength and mechanical properties of the materials. However, newer 3Y-5Y TZP zirconia products exhibit excellent material properties, with e.max ZirCAD Prime having 1200MPa flexural strength in the dentin zone and having similar translucency to IPS e.max Press LT¹⁷.

As CAD/CAM technology has continued to grow, the development of the Ti Base abutment has created limitless workflows and possibilities for restorations. Ti Bases can be utilized for both chairside and laboratory workflows. Scanbodies, which are removable implant sleeves that mark the timing of implants, can be used for both complete and hybrid digital workflows^{29,30}. Although Ti Bases continue to grow in popularity, there is little available literature outside of laboratory tests relating to the clinical guidelines or success of these abutments³⁰. Furthermore, a preliminary review of the literature reveals that no studies have examined the effect of screw channel angulations (SCA) on the fracture resistance of zirconia restorations cemented on Ti Base abutments. If the relationship of recommended SCA to Ti Base cemented crowns can be determined, then guidelines can be proposed for SCA before catastrophic fracture. Additionally, this may allow the clinician to avoid using a laboratory fabricated custom abutment which will save time and associated laboratory fees.

The purpose of this study was to investigate the effect of different screw channel angulations on the load to failure of zirconia restorations cemented to angled ti-bases. The null hypothesis was that the screw channel angulation would not have an effect on the load to failure.

MATERIALS AND METHODS

A Zimmer Biomet Certain Internal Connection 4.1mm platform implant analog (Nobel Biocare USA LLC, Yorba Linda, CA) was used as the implant platform throughout the study. A MIST S-link Ti Base (MIST Dental, Chantilly, VA) was placed on the analog and scanned using the manufacturer's scan marker with a laboratory optical scanner (Zirkonzahn USA Inc, Peachtree Corners, GA). A central incisor monolithic anatomical crown was designed and milled in e.max ZirCAD Prime (Ivoclar Vivadent Inc, Amherst, NY) using the Zirkonzahn software and Ivoclar PM7 mill (Ivoclar Vivadent Inc, Amherst, NY). The crown was of normal anatomic contour, with a crown height of 12mm and no less than 0.8mm thick at any given point, with a screw channel on the palatal surface designed. The cement space was set at 31 um. The crowns were sintered per the manufacturer's recommendations. Four different screw channel angulations — 0, 10, 15, and 20 — were tested on the Ti Base zirconia restoration (Figure 1). To create the different screw angulations, the designed crown were set at 10, 15, and 20 degrees from the long axis of the implant. The 0 group was used as the control. A power analysis was performed and it was determined that ten samples of each angulation would be tested for a total of 40 samples.

Digital Implant Model (DIM) analogs (NT Trading GmbH & Co, Karlsruhe, Germany), with an internal hex identical to Zimmer Biomet 4.1mm regular platform implant connection, were used as the implant analogs throughout the study. Titanium jigs were 3D printed from titanium alloy (Ti-6Al-4V) blocks approximately 59mm by 13mm by 9mm in size with a 4.25mm diameter hole in the center of the block to accommodate the implant analog size and shape (Arcam A1, GE Additive). One implant analog was placed into the titanium jig with the platform 2mm from the surface (Figure 2). Each zirconia crown was cemented to a ti-base with Panavia 21 resin cement (Kuraray America Inc, Houston, TX) according to the manufacturer's instructions. The Ti Base restoration was then seated onto the implant and torqued to the

recommended 20Ncm. The test model was fixed to a variable angle vice capable of applying load axially to the restoration at an angle of 135 degrees and placed in a universal testing machine (Instron, Northwood, MA, Figure 3). A continuous load was applied to each sample applied using the Instron at a rate of 2mm per minute. The loading point was at the midline 2 mm apical to the incisal edge simulating a 2 mm vertical overlap between the maxillary and mandibular incisors. Load was applied with a steel ball of 5mm in diameter until failure. The load at fracture for each specimen was confirmed via software (Bluehill 2 Software; Instron, Norwood, MA) which has a set displacement figure to note when fracture occurs. Statistical analysis was performed utilizing a statistical software program (SPSS 28; Armonk, NY). No artificial aging was used in this study.

RESULTS

A summary of the mean load to fracture, upper bound and lower bound confidence interval, and maximum load to fracture can be found in Table 1. Data is presented as mean +/- standard deviation in Newtons (N). In a descending order, the load to fracture was found to be: 10 degrees at 407.74 +/- 54.75 N, 15 degrees at 341.05 +/- 12.64 N, 20 degrees at 338.04 +/- 85.83 N, and the 0 degrees at 309.38 +/- 71.83 N.

A one-way ANOVA statistical analysis was initially selected to determine if the fracture load for zirconia crowns on titanium-bases was different for groups with differing screw channel angulations. One independent variable (crown angulation) was studied with the following screw angulations: 0 degrees ($n = 10$), 10 degrees ($n = 10$), 15 degrees ($n = 10$), and 20 degrees ($n = 10$). There were no outliers as assessed by a boxplot (Table 2) and the data was assessed by a Shapiro-Wilk test (Table 2, $p > .05$) showing the data to be normally distributed for each group. However the assumption of homogeneity of variances was violated according to the Levene's test for equality of variances (Table 3, $p < .001$). As a result, a Welch ANOVA (Table

4) was conducted to determine statistical differences between the angulation groups. Based on this analysis, there was a significant difference identified between the groups with $F(2, 27.716) = 88.851, p < .001$). Games-Howell post hoc analysis (Table 5) revealed that the greater fracture load of the 10 degree group (407.74 N) compared to the 0 degree group (309 N) and the 15 degree group (341 N) were statistically significant ($p < 0.001$). The difference in fracture load between 10 degrees and 20 degrees was not statistically significant ($p > 0.05$).

Multiple fracture locations were noted at the conclusion of testing. Out of the 40 samples tested, 35 samples had the crown fracture on the facial aspect at the tibase (Figures 4, 5). Three samples exhibited screw fractures with no damage to the crown or tibase. One sample had a combined crown-screw fracture and another sample had a broken crown-tibase. The table below exhibits the method of fracture by sample group (Table 6).

Discussion

The null hypothesis was rejected, as the fracture strength varied as the screw channel angulation changed. Furthermore, all of the tested samples had catastrophic failures, not only the groups with higher screw channel angulation.

Newer esthetic zirconia is becoming more popular due to their enhanced esthetic properties and flexural strength. Flexural strengths approaching 1200 MPa have been reported in the literature and by manufacturers¹⁷. In this study, the mean load to failure across all angulations was 349.05. This is well below reported flexural strengths of 1200 MPa. This can be explained by differences in test methodology and experiment design.

In the molar region, the maximum bite force can range from 300N-600N for healthy adults with natural dentition, although Nishigawa et al. found that nocturnal bruxism can exceed the amplitude of maximum voluntary bite force during the daytime.^{22,23} Knowing these ranges of bite forces and the physical properties of the different generations of zirconia, 3Y-TZP is

generally acceptable for posterior crowns and 5Y-TZP is generally acceptable for anterior crowns. By contrast, occlusal forces in the anterior can range much lower than in the posterior region with values ranging from 120-240 N.¹⁸⁻²¹ In this study, the lowest mean failure was the 0 degree screw channel angulation at 309 MPa. The lowest recorded failures in this study are still beyond the upper limit of occlusal forces achievable with anterior teeth. These findings support that using an angled screw channel implant supported crown not only is more convenient but can increase the fracture strength of the restoration as well.

In 2015, Thulasidas et al studied the effects of abutment design on the fracture resistance of zirconia abutments³². The study evaluated implant angulations of 20 degrees facial, zero degrees, and 20 degrees lingual while subjecting half the samples to autoclaving and thermocycling. They found the 20 degree facial group to have the highest fracture resistance and the 20 degree lingual group to have the least fracture resistance. While there are many similarities between this study and the present study, the major differences include the use of autoclaving and thermocycling, a polyether ether ketone (PEEK) block to hold the implant for testing, resin-modified glass ionomer to cement zirconia crowns to the zirconia custom abutment, and the facial implant inclination of a sample group. Another study released in 2020 by Garcia-Hammaker et al studied groups of 0 degrees and 25 degree screw channel angulation using NobelProcera one piece zirconia abutment crown³³. Their fracture mean values were 215.49N for the 25 degree ASC group and 420.51 for the zero degree group. Differences between this study and the present are the sample sizes, autopolymerizing acrylic to hold implant analogs, implant platforms, screw channel angulations, and fracture location of the failed samples.

Similar to other studies, a titanium bar was used to secure the implant analogs for testing. In future testing, a more ideal test could be completed with a resin or epoxy with an elastic modulus more similar to alveolar bone in the maxilla. Originally, cyclic loading was planned for testing but limitations to repair technicians for the testing machine and supply chain

issues shortened the available time to conduct testing. In a future study, cyclic loading with thermocycling would create results similar to the dynamic intraoral environment and occlusion.

Conclusion

Within the limitations of this study, the following conclusions can be made:

1. Changing the angulation of the screw access channel can alter the fracture strength of the zirconia implant supported crown.
2. Screw access channels of 10 degrees lingual to the long axis of the implant increase the fracture strength of zirconia implant supported crowns.
3. Regardless of the screw channel angulation the mean fracture load was higher than average occlusal loads in the incisor region.

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Load to Failure

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
0 degrees	10	309.38	71.830	22.715	258.00	360.76	199	432
10 degrees	10	407.74	54.749	17.313	368.58	446.91	318	497
15 degrees	10	341.05	12.642	3.998	332.01	350.09	318	361
20 degrees	10	338.04	85.828	27.141	276.64	399.44	157	437
Total	40	349.05	70.381	11.128	326.54	371.56	157	497

Table 1 shows the load to failure values in newtons (N).

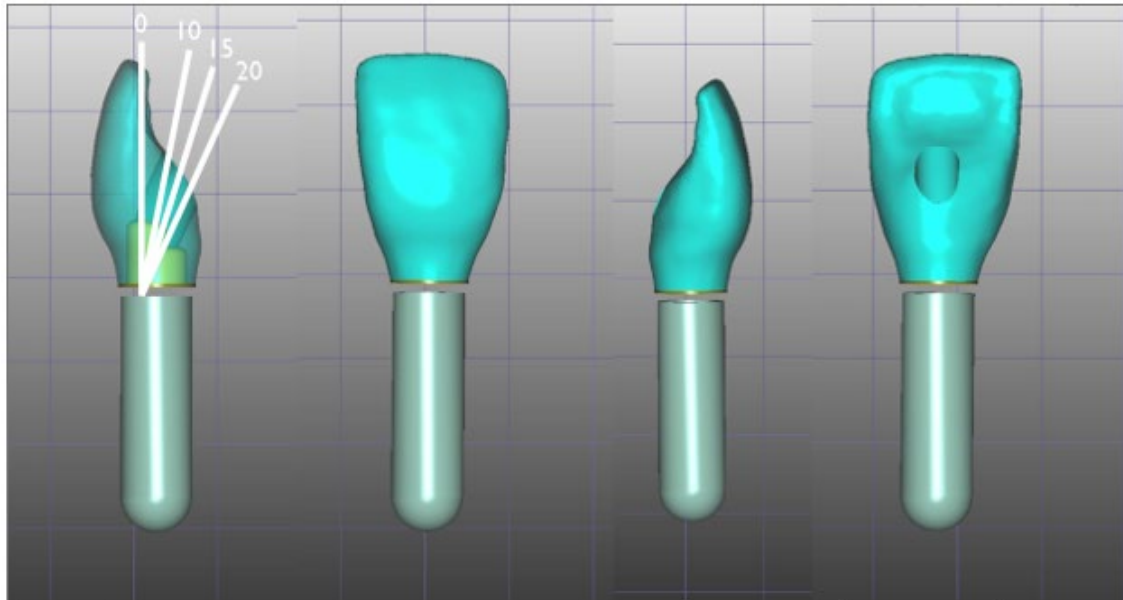


Figure 1

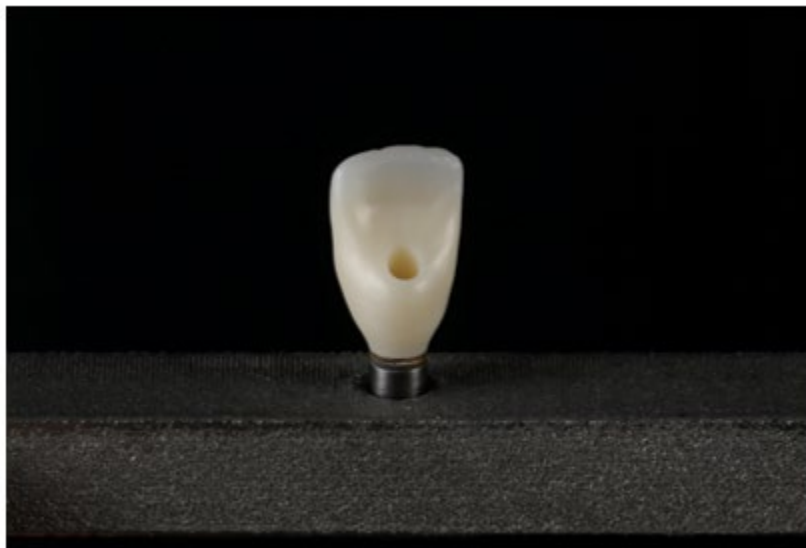


Figure 2



Figure 3

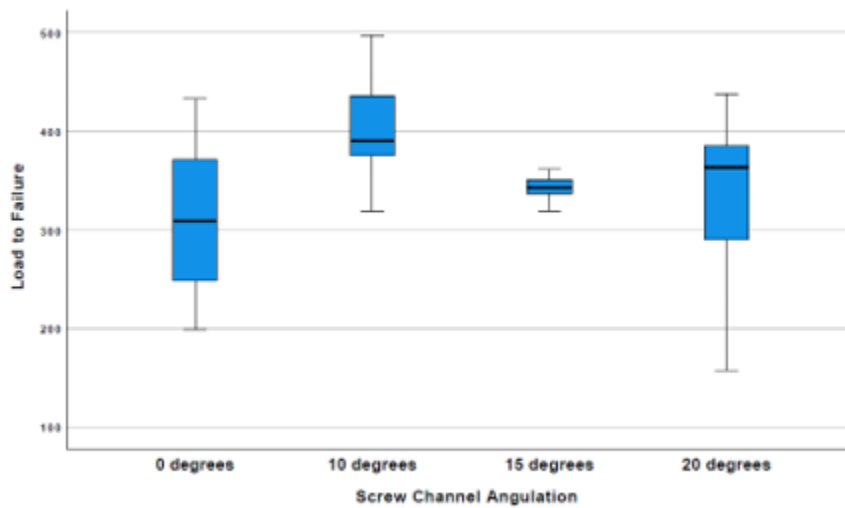


Table 2

Test of Homogeneity of Variance

		Levene Statistic	df1	df2	Sig.
Load to Failure	Based on Mean	4.197	3	36	.012
	Based on Median	2.952	3	36	.046
	Based on Median and with adjusted df	2.952	3	23.948	.053
	Based on trimmed mean	3.985	3	36	.015

Table 3

Robust Tests of Equality of Means

Load to Failure

	Statistic ^a	df1	df2	Sig.
Welch	5.057	3	15.952	.012

a. Asymptotically F distributed.

Table 4

Dependent Variable: Load to Failure

Games-Howell

(I) Screw Channel Angulation	(J) Screw Channel Angulation	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0 degrees	10 degrees	-98.362*	28.560	.015	-179.64	-17.09
	15 degrees	-31.672	23.064	.543	-102.83	39.48
	20 degrees	-28.663	35.392	.849	-128.99	71.67
10 degrees	0 degrees	98.362*	28.560	.015	17.09	179.64
	15 degrees	66.689*	17.769	.017	12.29	121.09
	20 degrees	69.698	32.193	.177	-22.88	162.28
15 degrees	0 degrees	31.672	23.064	.543	-39.48	102.83
	10 degrees	-66.689*	17.769	.017	-121.09	-12.29
	20 degrees	3.009	27.434	.999	-81.92	87.94
20 degrees	0 degrees	28.663	35.392	.849	-71.67	128.99
	10 degrees	-69.698	32.193	.177	-162.28	22.88
	15 degrees	-3.009	27.434	.999	-87.94	81.92

*. The mean difference is significant at the 0.05 level.

Table 5

	Crown fracture	Screw fracture	Crown-screw	Crown-TiBase
0	10			
10	7	2	1	
15	9	1		
20	9			1
Total	35	3	1	1

Table 6



Figure 4



Figure 5