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Title: The effect of cantilever forces on various zirconia restoration heights cemented to a Ti base

Running Title: Effect of cantilever size on anterior Ti base restorations.

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ABSTRACT:

Purpose: The purpose of this study is to test load to failure on varying heights of zirconia crowns cemented to Ti base abutments. It will investigate the effect of cantilever forces produced on the unsupported restoration extending beyond the abutment. Three different heights will be tested.

Materials and Methods (should brand names be included or : Three crown heights of 13mm, 14.5mm, and 16mm were designed with Zirkonzahn software for a Mist brand Ti base fitting a 4.1mm regular platform implant. Fourty-eight samples were milled in Zircad Prime zirconia, each height group containing 16 crowns. The crowns were cemented to a Ti base using Panavia 21 resin cement, torqued to an implant analog and placed into a custom titanium jig. A universal testing machine (Instron) was then used to load the sample until any component of the restoration failed. The process was repeated for each of the sample.

Results: The highest mean load to fracture found was for the 13mm group (G13) at 509.25 +/- 71.91 N, followed by the 14.5mm group (G15) at 268.22 +/- 27.76 N, and lastly by the 16mm group (G16) at 253.14 +/- 25.97 N. A statistical significance ($p<.001$) was found between the 13mm group and the others, but no statistical significance was found between the 14.5mm and 16mm groups.

Conclusions: Within the limitations of this in vitro study the mean failure load was significantly higher in the group with the shortest incisor height.

INTRODUCTION

Loss of a tooth is a problem that affects many individuals. Restoring the edentulous space with a fixed restoration has become a prime objective for most patients and clinicians. Often, the teeth adjacent to an edentulous site are healthy or minimally restored, and preparation for a fixed partial denture can extend risk and complications beyond a single missing tooth. Dental implants have made it possible to restore edentulous sites with high levels of success, leaving adjacent teeth intact.[1] Titanium abutments are commonly used to support implant restorations. However, this can lead to an unaesthetic result in which the overlying tissue can appear grey. To battle this downfall, implant manufacturers created zirconia abutments.[2,3,4] Unfortunately the physical properties of zirconia and titanium implants have been found to cause wear at the abutment-implant interface. The brittle nature of the zirconia can also lead to fractures of the abutment.[5] Titanium abutments provide a better interface due to the compatible surface and better adaptation at the junction of the platform and abutment. This can be seen in a study by Baldassarri et al, in which they found the mean gap between the implant platform and a zirconia abutment to be three to seven times higher than the gap between the implant platform and a titanium abutment.[6]

Since the introduction of yttrium oxide partially stabilized tetragonal zirconia polycrystalline (Y-TZP) in dentistry in the early 1990s, this material has become an increasingly popular framework and restorative material due to its high strength and esthetic appearance.[7] Based on in vitro studies, its flexural strength ranges from 900 to over 1200 MPa with a fracture toughness of 9-10 MPa.[8-11] Monolithic zirconia restorations have eliminated the primary cause of layered ceramic failure, thus chipping of the veneering porcelain can now be a forgotten concern. Zirconia also can mask underlying discoloration and has been proven to be highly biocompatible with gingival tissues.[12]

The failures of zirconia abutments and ever-present need for optimum esthetics led to the creation of hybrid abutments that create an interface to the titanium implant connection and ceramic abutment or crown. This combination is simply called a Ti base. The two parts can be joined with a cement, preferably a resin cement. Use of a Ti base will reinforce and create higher fracture resistance of a zirconia abutment as shown by Chun et al.[13] These abutments offer the best of both materials; they combine the camouflage-ability of zirconia with the successful titanium abutment implant interface. Ti base restorations can overcome esthetic complications without compromising implant stability or tissue health. As CAD/CAM technology has gained popularity and efficiency within dental practices, manufacturers have integrated these Ti bases into digital workflows.

This restorative option has many benefits, but it does come with potential complications. Ti base abutments come in fixed heights regardless of the final height of the coronal restoration, which can leave a significant amount of unsupported restorative material creating a cantilever. Oblique forces on this cantilever could concentrate stress at the neck of the implant.[14,15] Some Ti base manufacturers publish recommended ratios or contraindications for use of their products. Dentsply Sirona recommends a ratio of restoration to implant of 1:1.25, however some other third party manufacturers do not have recommendations for restoration height for Ti base restorations.[16] Cantilevers that are not accounted for in the treatment planning process can cause mechanical and biologic complications such as fracture of restorations, screw loosening, and de-bonding of the restoration or even bone loss and implant failure.[15] The longer the cantilever, the greater the force that can be generated. Current literature has developed two terms to categorize this restorative space of an implant: crown to implant ratio and crown height space.[14,15,17] Crown to implant ratio (CIR) is a ratio of the length of the crown in comparison to the length of the implant. The crown height space (CHS) is measurement from crest of bone to the occlusal incisal plane.[14]

There is sparse literature investigating monolithic zirconia as an implant restorative material on Ti bases. A preliminary review of the literature also reveals only one similar study that looked at the effect of off-axis forces on various zirconia restoration heights cemented to Ti bases.[18] However, this study reviewed the effects of cantilevers and oblique force in the posterior region. Other studies have looked at the effect of CIR or CHS on the survival of restorations and implants, but did not address Ti base use in the anterior region.[14,15,17,18,19] Less similar studies have examined the effect of cement type and abutment height on retention of crowns on titanium abutments, with resin cement creating better retention.[13,20] Bernal et al, investigated the height and occlusal convergence of traditional titanium abutments on retention and resistance, finding that traditional prosthodontic principles of teeth apply to titanium abutments as well.[21,22] However, these too do not address the use of Ti bases and effects of cantilever forces.

Literature is lacking for the use of Ti bases with zirconia restorations in the anterior region. If the ratio of recommended zirconia restoration height to Ti base height can be determined, then guidelines can be proposed for restoration height limitations to prevent catastrophic failures with or without cantilever forces present. These guidelines will reduce the incidence of restoration failures, thus saving time, money, and reducing the absence of Soldiers from their units. As the use of Ti base abutments increases, and with the advent of multiple digital workflows, all aspects of this restorative option must be investigated. Often, an implant is placed in a more apical position to allow for a better emergence profile or in some clinical situations it is placed apical because of a severe vertical ridge defect and a low smile line. This leaves a large crown height space between the implant platform and the anticipated incisal edge.

The purpose of this study is to investigate the effect of cantilever forces produced from an unsupported restoration on a Ti base abutments. This will be done through testing the load

to failure on three different heights of zirconia crowns: 13mm, 14.5mm, and 16mm. The null hypothesis is that the height of the restoration will have no effect on the load to failure.

Materials and Methods

A power analysis was performed based on results from a similar study.[20] A sample size of 16 was determined to be sufficient.

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). Implant analogs were placed and secured into the jig with the platform flush to the block surface (Figure 1). A Mist (Imagine Milling Technologies LLC, Chantilly, VA) scan body was placed on the analog, and scanned using a Zirkonsahn laboratory optical scanner (Zirkonzahn, Gais, Italy). A maxillary central incisor monolithic crown of 13mm was designed with Zirkonzahn software (Zirkonzahn, Gais, Italy) with an internal fit for a 5.5 mm Mist IC L-Link Ti base. The same design was used with an increase of incisal height to create two more designs with the specified heights 14.5mm and 16mm. (Figure 2) These heights were chosen to simulate a short, normal, and tall incisor (assuming implant placement 3mm apical to CEJ).[23] The crown was of normal anatomic contour a standardized 0.8mm in the apical 1.5mm for all sample heights, no less than 0.8mm at any given point, and a cement space of 31 um. There was a screw access channel added to the palatal surface of the zirconia crown with a 0 degree inclination to the screw access. The design STLs were sent to be milled by the Army Dental Lab in eMax Zircad Prime (Ivoclar Vivadent, Amherst, NY) The crowns were dry milled with the PrograMill PM-7 (Ivoclar Vivadent, Amherst, NY). The samples were sintered per the manufacturer's recommendations in a Zenotec Fire P1 (Wieland, Pforzheim, Germany). Sixteen

samples of 13mm and 14.5mm heights, and 16mm heights were created for a total of 48 samples.

Each zirconia crown abutment's intaglio was sandblasted with 50 μm Al_2O_3 at 1.5 bar, steamed cleaned, treated with Z-prime (BISCO Dental, Schaumburg, IL). The Ti bases were also sandblasted lightly with 50 μm Al_2O_3 at 1.5 bar. The crowns were cemented to a Ti base with Panavia 21 TC adhesive resin cement (Kuraray Dental, New York, NY).[24] The Ti base restoration was seated onto the DIM analog and torqued to the recommended 20Ncm with a torque gauge. 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 an Instron (Model E10000) machine (Figure 3). A load was applied at a rate of 0.3mm per second (2mm/min). 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.[25] Load was applied until failure (Figure 4). Blue Hill software was used on the samples to collect the data points and load at failure (Bluehill 2 Software; Instron, Norwood, MA). Statistical analysis was performed by using a statistical software program (SAS 9.4; SAS Institute Inc). Mean failure loads were calculated and a one way ANOVA test performed. No artificial aging was used in this in vitro 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. The highest mean load to fracture was found in the 13mm group (G13) at 509.25 +/- 71.91 N, followed by the 14.5mm group (G15) at 268.22 +/- 27.76 N, and lastly by the 16mm group (G16) at 253.14 +/- 25.97 N.

A one-way ANOVA statistical analysis was initially selected to determine if the fracture load for zirconia crowns on Ti bases was different for groups with different heights of crowns.

One independent variable (crown height) and three different heights were studied: 13mm (n = 16), 14.5mm (n = 16), and 16mm (n = 16). There were no outliers, as assessed by a boxplot (Figure 5) and the data was normally distributed for each group, as assessed by Shapiro-Wilk test (Table 2, $p > .05$). 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 height 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 G13 compared to G15, at 241 N, and compared to G16, at 256.1 N, were statistically significant ($p < 0.001$). The difference in fracture load between G15 and G16, at 15.08 N, was not statistically significant ($p>0.05$)

All of the specimens failed by the screw stripping or breaking, no other modes of fracture were noted. However there was some warping of the titanium after the abutment screw broke, before the machine aborted applying force. (Figure 6).

DISCUSSION:

In this study, the effect of increasing restoration height of zirconia crowns cemented to a fixed height Ti base was investigated. Ti base restorations are becoming increasingly popular with their incorporation into digital work flows and the fact that they can reduce the amount of treatment time by eliminating the need for a custom titanium abutment. However little guidance or literature addresses limitations of their use. Based on the results of this study, the null hypothesis was rejected. It was found that as the height of the restorations increased, and with it an increase in cantilever forces, the load to failure decreased. There were differences noted between all groups, however only the 13mm height showed a statistically significant difference ($p<.001$) than the other groups with a mean of 509.25 N. The mode of failure was found to be screw warping or breaking for all samples regardless of height (Figure 6). Some warping of the titanium was noted in some samples, but it did not lead to failure of the restoration, and was

thought to have occurred after the screw broke and before the Instron machine stopped pushing as seen in Figure 4.

Only sparse literature exists when searching for effects of Ti base restoration height. However, there is an increase of similar studies that have similar findings to the present study that discuss the overarching issues of cantilever forces with regards to CIR and CHS on single implant restorations.[14,15,17-19] Misch et al wrote a consensus report in 2000 about the negative effects of excessive CHS and oblique forces, and that an increased height of a restoration only creates a force magnification at the neck of the implant. They noted that a 100 N force angled at 12º on a 15 mm crown is actually 315 N once the cantilever force was calculated, concluding that an ideal CHS was 8-12 mm. Misch et al suggests that preprosthetic augmentation of sites should be heavily considered to forgo the issue of excessive CHS.[15] As our study increased restorations beyond 13 mm in height, we did find a statistically significant drop in the load until failure within our restorations, supporting the ideal range of CHS supported by Misch el al.

Nissan et al also explored CIR and CHS, and found that CHS was a better predictor of success than CIR because it was more related to lever arm mechanics. They found that for each increase in CHS of 1mm, the cervical load will increase by 20%. They showed that stress will concentrate at the neck of the implant, more specifically at the implant-prosthetic junction. They also found prosthetic screw failures occurred more often after a crown was 15 mm tall regardless of the implant length.[17] Though a CoCrMo alloy was used for their crowns, the principle findings of increased CHS are consistent with our results that as the crown length increased we saw prosthetic complications occurring at lower forces. CHS rather than CIR also applies more to our study since we used a standard analog held within a titanium jig, creating a true lever arm.

In two more recent studies, Bulaqi et al and Urdaneta et al both examined increasing cantilevers and CHS on single implant-supported restorations. Bulaqi et al performed a finite element analysis and also found the stresses of oblique forces to be concentrated at the neck of

the implant. Both studies found that an increase in cantilever forces creates a larger non-uniform stress and force magnitude that leads to increased screw loosening, more than any other complication. Bulaqi et al state that these forces are indeed most destructive to the screw by contributing to screw loosening and fatigue fractures, which helps support the 100% screw failures of the present study. These studies differ from the present study, however, as they did not assess Ti base restorations, addressed the posterior region, and involved cyclic fatigue rather than a linear static force application.

A study by Burak et al was similar to the present study in that they assessed zirconia premolar crowns cemented to Ti bases and subjected the restorations to oblique loading. The clinical implications of their study indicated that extending a restoration beyond 14mm will increase the risk of screw or implant failure. Our findings also indicate that there was a statistically significant decrease in load to failure from 13mm to 14.5mm. The specimens for this study replicated premolar crowns, while the present study replicated a central incisor, however the concept of creating a cantilever force was the same. Their results, along with those of the present study, show that the use of Ti bases with taller restorations still face the same biologic and mechanical complications as custom abutments and restorations.

It is clear that the results of this study were in agreeance with previous studies that addressed cantilevers and CHS. Though this study is only an in vitro study, it holds clinical relevance that is consistent with previous studies which found that cantilever forces can have a deleterious effect on the implant restoration and the surrounding bone. Screw loosening and fracture was the mode of failure for all the samples in this study, similar to results of similar studies. Stresses are magnified at the neck of the implant and creating asymmetrical tension and force on the screw.[14] Based on these findings, clinicians should be cautioned to preprosthetically plan to mitigate risk for clinical situations with excessive bone loss and a large restorative space.

Clinical relevance is also found when we see that the mean loads at failure for all groups were still above the average anterior masticatory ranges reported in literature, listed at approximately 120-240N.[26-29] This shows that Ti bases could potentially be a valid treatment option even when there is a larger crown height space to restore. However, patient selection may be critical to avoid those patients with parafunctional habits, and proper elimination of excessive oblique force on the restorations must be ensured to prevent amplified forces on the bone and abutment.

There are limitations to this study. This study was in vitro and no simulated aging was performed on the specimens. The force applied was a linear static force not cyclic loading. These limitations negate the idea that the restoration does not only need to withstand strong loading forces but also fatiguing activities and function within the oral environment. A titanium jig was used to hold the implant restoration, thus our study lacked the impact of the elastic nature of bone to be included within our findings. Future studies are needed that address the impact of the Ti base height on the failure load and simulated aging. Also, studies conducted within a material similar to bone should be done as these could provide results closer to those found in vivo.

CONCLUSION:

Within the limitations of this study it can be concluded that increasing the height of a Ti base restoration can reduce the load necessary to cause failure of the restoration. As found in previous studies, restorations above 14mm begin to show more risk of prosthetic complications at lower forces.

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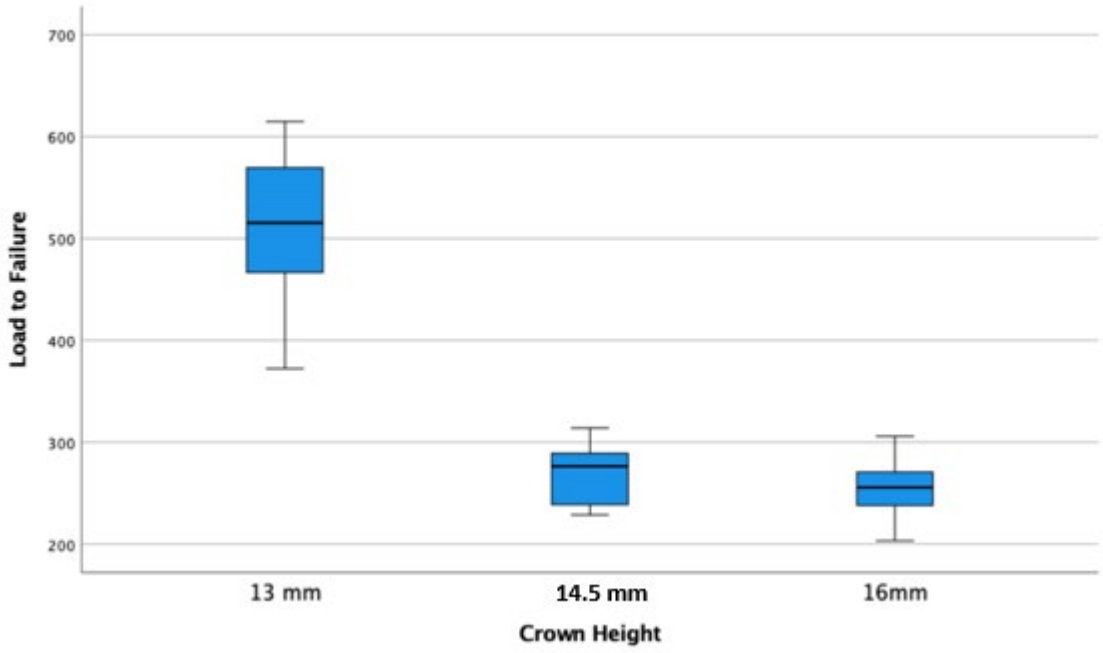

Figure 5: Boxplot

Descriptives

	Crown Height			Statistic	Std. Error
Load to Failure	13 mm	Mean		509.25	17.978
		95% Confidence Interval for Mean	Lower Bound	470.93	
			Upper Bound	547.57	
		Std. Deviation		71.912	
	14.5mm	Mean		268.22	6.941
		95% Confidence Interval for Mean	Lower Bound	253.43	
			Upper Bound	283.01	
		Std. Deviation		27.763	
	16mm	Mean		253.14	6.494
		95% Confidence Interval for Mean	Lower Bound	239.30	
			Upper Bound	266.98	
		Std. Deviation		25.974	

Table 1: Descriptive Data

Tests of Normality

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Crown Height	Statistic	df	Sig.	Statistic	df	Sig.
Load to Failure	13 mm	.086	16	.200*	.969	16	.822
	14.5mm	.161	16	.200*	.927	16	.219
	16mm	.164	16	.200*	.951	16	.509

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table 2 Tests of Normality

Tests of Homogeneity of Variances

		Levene Statistic	df1	df2	Sig.
Load to Failure	Based on Mean	9.438	2	45	<.001
	Based on Median	8.742	2	45	<.001
	Based on Median and with adjusted df	8.742	2	25.134	.001
	Based on trimmed mean	9.197	2	45	<.001

Table 3 Levene Test for Homogeneity of Variances

Robust Tests of Equality of Means

Load to Failure

	Statistic[a]	df1	df2	Sig.
Welch	88.851	2	27.716	<.001

a. Asymptotically F distributed.

Table 4: Welch ANOVA

Multiple Comparisons

Dependent Variable: Load to Failure

Games-Howell

(I) Crown Height	(J) Crown Height	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
13 mm	14.5mm	241.030*	19.271	<.001	192.15	289.91
	16mm	256.114*	19.115	<.001	207.52	304.71
14.5mm	13 mm	-241.030*	19.271	<.001	-289.91	-192.15
	16mm	15.084	9.505	.267	-8.35	38.52
16mm	13 mm	-256.114*	19.115	<.001	-304.71	-207.52
	14.5mm	-15.084	9.505	.267	-38.52	8.35

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

Table 5: Post-Hoc Tests

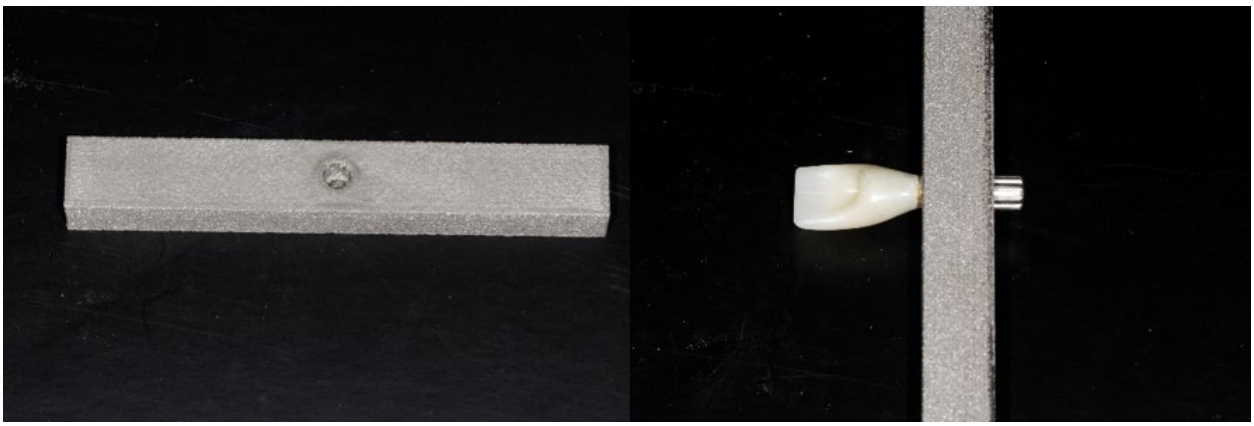

Figure 1. 3D printed titanium jig and specimen loaded for example

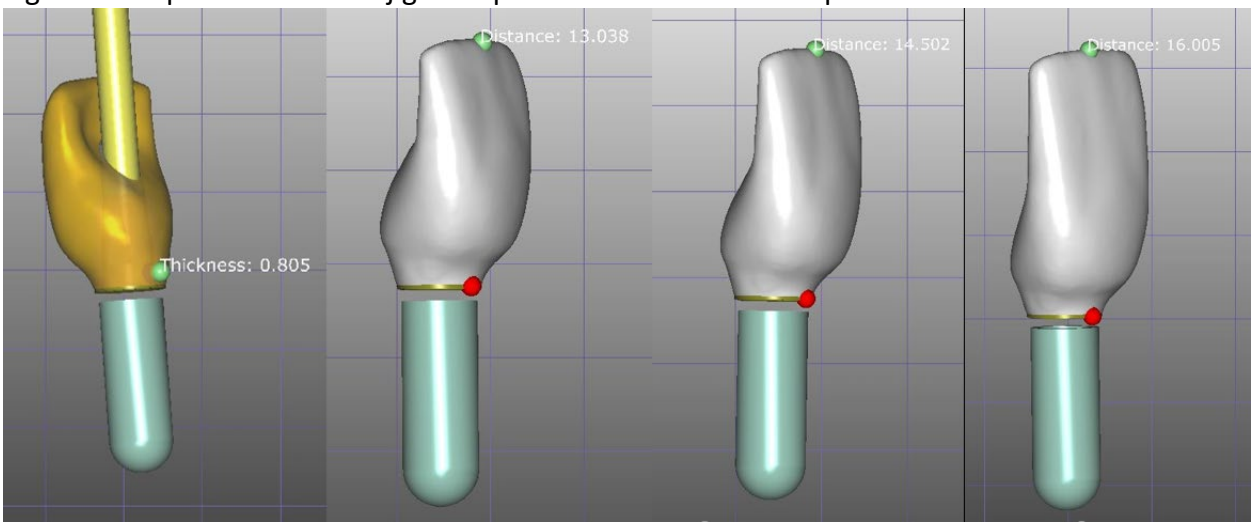

Figure 2. Crown design STLs

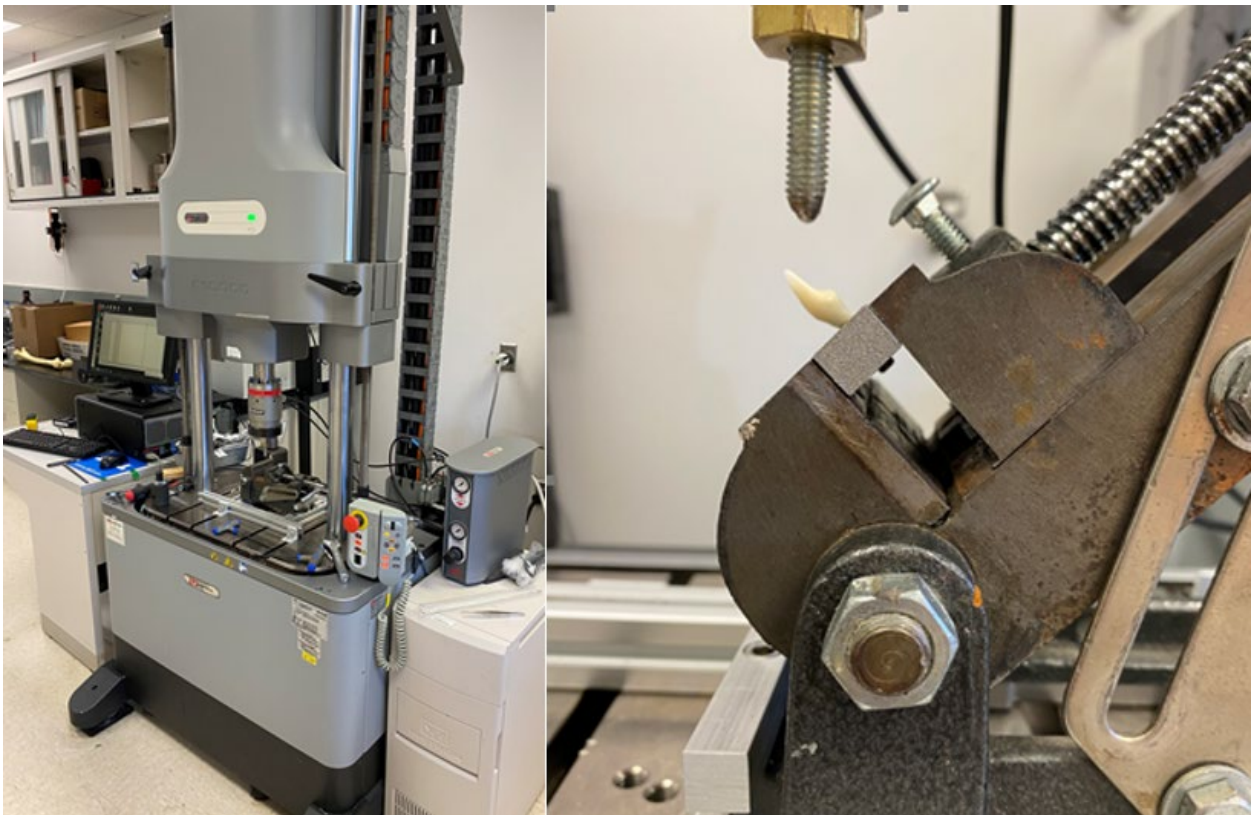

Figure 3. The Instron machine and the vice used

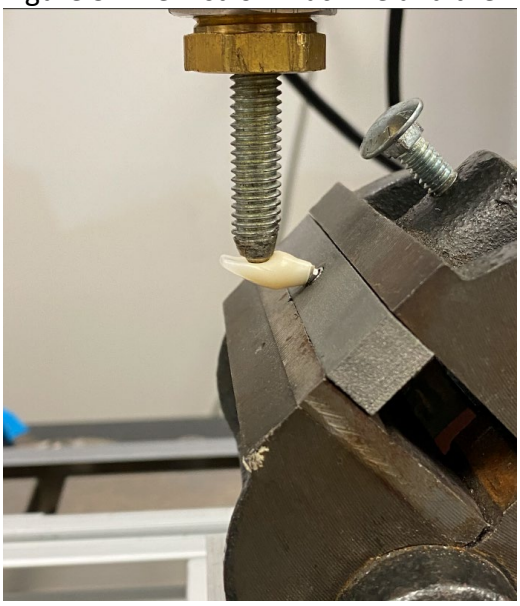

Figure 4. Load until failure

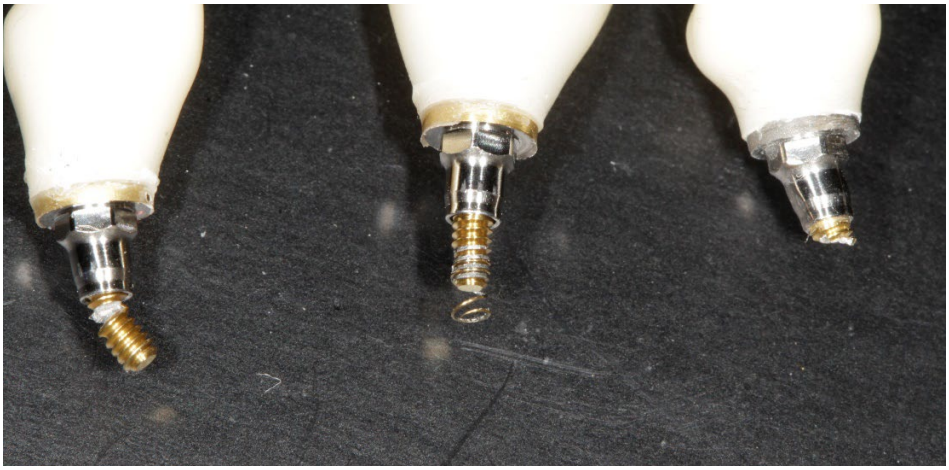

Figure 6. Mode of failure, screw breaking or stripping