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THESIS APPROVAL PAGE FOR MASTER OF SCIENCE IN ORAL BIOLOGY

Title of Thesis: Effect of Axial Wall Heights and Degrees of Total Occlusal Convergence on the Retention of 4Y Zirconia Crowns Adhesively Bonded to 4Y Zzirconia Abutments

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Master of Science Degree
May 21, 2021

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Effect of axial wall heights and degrees of total occlusal convergence on the resistance of 4Y zirconia crowns adhesively bonded to 4Y zirconia abutments.

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ABSTRACT

Statement of Problem: Currently, no published data exists to provide clinical guidance on decisions relative to axial wall height (AWH) and degree of total occlusal convergence (TOC) regarding 4Y-TZP zirconia crowns that bonded to 4Y-TZP zirconia custom implant abutments.

Purpose: The purpose of this study was to quantify the effect that AWH and degree of TOC have on the resistance to dislodgement of milled 4Y-TZP zirconia crowns adhesively bonded to 4Y-TZP zirconia custom implant abutments.

Material and Methods: Eight groups of ten 4Y-TZP zirconia crown (iMILL Zr, Imagine USA, Fullerton, CA) and abutment pairs (n=10) were fabricated. Each group differed in AWH (1mm, 2mm, 3mm, 4mm) and TOC (7°, 15°) of the abutment and corresponding crown. Each zirconia abutment and corresponding crown were adhesively bonded using the Panavia V5 (Kuraray North America, Houston, TX) resin cement system according to manufacturer’s recommendation. Study samples were thermocycled for artificial aging, then mounted into the Instron Universal Testing Machine (Instron, Norwood, MA) where force applied at 45° to the long axis of the sample to failure (fracture or debonding). The mode of failure and load at which failure occurred were recorded.

Results: 80% (64 of 80) of samples across all groups failed due to debonding as opposed to fracture (16 of 80). The sample group with 7° TOC and 4mm of AWH yielded the highest mean load at failure, and the group with 15° of TOC and 2mm of AWH yielded the lowest mean load at failure. Statistically significant difference of load at failure was observed between 7° and 15° of TOC groups, however, no statistical difference was found among different AWH groups.

Conclusions: This in vitro study indicates the resin bond strength is sufficient to withstand the dislodging force of a milled 4Y TZP zirconia crown bonded on a milled 4Y-TZP zirconia custom implant abutment that lacks traditional resistance form. The difference in the degree of TOC made significant difference while the difference in AWH did not contribute to significant difference in resistance to dislodgement of crowns.

Clinical implications: When using a split file technique to fabricate 4Y-TZP single-unit implant-supported restorations, an AWH of ≥3mm with a TOC ≤15 degrees will resist dislodging forces when the crown and abutment are adhesively bonded together. This allows for an edentulous space with limited vertical restorative space to be restored using the split file technique.

INTRODUCTION

Growing demands for esthetically and functionally superior dental restorations have led patients to choose implant-supported restorations for edentulous areas. When compared to conventional fixed or removable prostheses, not only does modern implant therapy offer superior biological and functional treatment options, it yields long-term success and survival rates above 95% (Torabinejad, Anderson et al. 2007, Buser, Sennerby et al. 2017). Available implant restoration option for replacing a single missing tooth is either a cement-retained or screw-retained implant crown. From the earliest stages of implant dentistry, there have been continuous debates surrounding screw-retained or cement-retained prosthetic restorations.

Over the years, screw-retained implant crowns have been fabricated via lost wax technique, as well utilizing CAD/CAM technology using materials such as gold, lithium disilicate, zirconia, or other ceramic materials. Advantages of the screw-retained implant prosthesis include ease of restoration retrieval and overcoming limited restorative space issues. However, the inconvenience of intraoral adjustments on crown restorations and unaesthetic access holes on the incisal or occlusal surfaces are major drawbacks of choosing the screw-retained implant crowns (Michalakis, Hirayama et al. 2003). Additionally, screw-retained restorations cannot be used when the axis of the placed implant is too divergent from the insertion axis of the restoration.

In contrast to screw-retained restorations, cement-retained implant restorations have crowns cemented onto either stock abutments or custom abutments. The cement-retained implant crown offers the following advantages: easier chairside adjustment and delivery, no occlusal or incisal screw access holes, and ability to correct off-angle implant placement. However, the major downfall of the cement-retained implant prosthesis is the susceptibility of the peri-implantitis due to retained excess cement (Wittneben, Joda et al. 2017). Due to the limited access of subgingival abutment-crown junctions, it is difficult to completely remove excess cement from the cement-retained implant supported restorations. Research suggests that the cement remnants may induce peri-implantitis (Wilson, T. G. Jr. 2009). One systematic review of clinical studies found that peri-implantitis and mucositis may occur in 1.9% to 75% of cemented implant restorations with 33% to 100% associated with excess cement (Staubli, Walter et al. 2017).

In order to minimize undetected residual cements on cement-retained implant restorations, custom abutments are utilized to limit the subgingival placement of crown-abutment junction (Bidra and Rungruanganunt 2013, Cooper, Stanford et al. 2016). Traditionally, custom implant abutments were fabricated with metal (gold, titanium) to prevent fracture from excessive loading. Sailer et al reported that metal abutments presented esthetic complications, describing grayish discoloration of the peri-implant mucosa. The use of ceramic or zirconia abutments improves esthetics while allowing for optimal adaptation between the margins of the restoration and the soft tissue. To address both longevity and esthetics, zirconia abutments are used to replace the less appealing metal substrate abutments (Sailer, Philipp et al. 2009).

Zirconium is a soft silver-colored metal found as a mineral called zircon ($ZrSiO_4$). Zircon can be processed to create zirconia by melting the sand at very high temperatures, typically above 2,600ºC, in an electric arc furnace to form molten zirconia, also known as zirconium oxide (ZrO_2). Zirconia crystals can be organized in three different patterns: monoclinic, tetragonal, and cubic. By adding yttria to ZrO_2 stabilizes the crystalline structure at room temperature and create a yttria-stabilized tetragonal zirconia polycrystalline (Y-TZP) ceramic. The tetragonal to monoclinic transformation (phase transformation) improves the Y-TZP toughness and prevents further propagation of cracks by applying compressive stress at the tip of cracks via a positive volumetric change (Hannink 2000). Y-TZP zirconia, in general, can be classified into three groups by molar percentage of yttria content (3,4,5), and the mechanical and physical properties are determined by the amount of yttria in zirconia. Y-TZP yields a high fracture toughness, from 2.2 to 4.5 MPa, and a flexural strength of 600– 1500 MPa (Christel, Meunier et al. 1989, Guazzato, Albakry et al. 2004). Y-TZP is widely used for ceramic crowns and abutments as it claims superior mechanical properties (Miyazaki, Nakamura et al. 2013, Sellers, Powers et al. 2017).

To meet the growing demands for both esthetics and long-term durability, 4Y-TZP zirconia has become a widely used restorative material for crown restorations. Compare to traditional 3Y-TZP zirconia, 4Y-TZP has 25% to 50% increase in cubic content, less porosity, and increased size of cubic grains, which all led to better light transmission. 4Y-TZP has flexural strength of 600 to 900 MPa and fracture toughness of 2.5 to 3.5. 4Y-TZP zirconia is comparable in translucency and yield higher flexural strength compare to lithium disilicate (Y. Zhang and B.R. Lawn 2018). 4Y-TZP restorations demonstrated acceptable fracture resistance for use as full contour crown and implant abutment, and it may be adhesively bonded. 4Y-TZP zirconia restoration material is available as a form of monolithic block or in a puck that can be milled via CAD/CAM technology. The partially sintered 4Y TZP zirconia is milled into a crown or implant abutment, then further sintered at high temperature between 1400-1600˚C, which produces approximately 20% shrinkage in total volume (Denry 2008, Fisler 2003).

Abutment form is key to achieving maximum resistance to dislodgement for a full contour crown restoration. For ideal resistance form, the abutment should have axial wall angulation between 10 to 20 degrees with a minimum of 3 mm of axial wall height in premolar and anterior regions, and 4 mm in molar regions (Goodacre, Campagni et al. 2001). The ideal resistance form and/or the auxiliary features allow traditional luting systems to micromechanically lock the interfaces of abutment and restoration for retention. However, sometimes providers face the challenge of restoring an edentulous area where restorative space is limited. Misch states crown height space (CHS) should be at minimum 8mm vertically to properly restore the edentulous space for implant supported restoration (Misch, Goodacre et al. 2005, Misch, Goodacre et al. 2006). With CAD/CAM, providers have the ability to adjust the parameters of restorations and abutments. To reduce the peri-implantitis and to achieve the ideal emergence profile, 2mm of biological dimension is recommended between the implant platform and the crown margin. In addition, manufactures recommend keeping all ceramic restorations' occlusal thickness minimum of 2mm to prevent fracture from loading. This only leaves providers with the option to change the axial wall height of the abutment. When an ideal abutment resistance form cannot be achieved, resin cement could be utilized to bond the crown to the abutment. A recent study showed that bonding crowns to tooth structure with resin cement may provide sufficient retention of ceramic restorations to the tooth when the resistance form is less than ideal (Morimoto, Rebello de Sampaio et al. 2016).

In order to use resin bonding systems on 4Y-TZP zirconia ceramic crowns, surface conditioning treatment is necessary. Zirconia abutment surfaces can be abraded with 50 µm alumina airborne-particle for 10 to 15 seconds. This conditioned surface is ready for an acidic adhesive monomer to provide adhesive bonding of zirconia to the resin cement. The phosphate ester group of the acidic monomer(10- Methacryloyloxydecyl dihydrogen phosphate) forms strong ionic bonds to metal oxides of the zirconia abutment surface to allow resin bonding when polymerized (Blatz, Chiche et al. 2007, Sellers, Powers et al. 2017).

Resin bonding is possible between zirconia crowns and zirconia abutments. There have been numerous studies measuring the bond strength of a zirconia crown bonded to a natural tooth (Blatz et al. 2018, Russo et al. 2019), but no known research to date has investigated the effect of varying AWHs and the degrees of TOC on retention of adhesively bonded zirconia crowns to zirconia implant abutments.

In this study, the impact of varying in AWHs and degrees of TOC on retention of a milled 4Y-TZP zirconia crown adhesively bonded to a 4Y-TZP zirconia custom implant abutment will be investigated.

SPECIFIC AIMS

The primary propose of this study is to determine if bonding can reliably compensate for deficient resistance form. Specifically, this study seeks to evaluate and quantify the effect that AWH and degree of TOC have on the resistance to dislodgement displayed by crowns bonded to implant abutments using milled 4Y-TZP zirconia as the material to fabricate both the abutments and the crowns.

HYPOTHESIS

Null hypothesis: There is no statistically significant difference in the amount of force required to dislodge milled 4Y-TZP zirconia crowns bonded to milled 4Y-TZP zirconia abutments when the AWH of the abutment and the TOC of those axial walls varies.

Alternative hypothesis: The amount of force required to dislodge milled 4Y-TZP zirconia crowns bonded to milled 4Y-TZP zirconia abutments differs significantly when the AWH of the abutment and/or the TOC of those axial walls varies.

MATERIALS & METHODS

Sirona InLab 16.1 design software was used to design “coping” type restorations that served as the basis for the design abutments. The designs were exported as digital STL files that were sent to a milling center (Imagine Milling, Chantilly, VA) for production. The study consisted of eight test groups. These eight groups resulted from the combination of four AWH-groups and two different degrees of TOC. Abutments were designed with a shoulder margin with 1.5 mm axial depth. The designed AWH were 4 mm, 3 mm, 2 mm, and 1 mm and the designed TOC variations were 7 degrees and 15 degrees [Figures 1 & 2]. Abutments were fabricated from 4Y-TZP zirconia (iMILL Zr, Imagine USA, Fullerton, CA). The groups consisted of 10 samples each (N=10). Each custom abutment sample was designed with a 20mm extension base apical to the finish line of the abutment. This extension was utilized for fixation in the testing device.

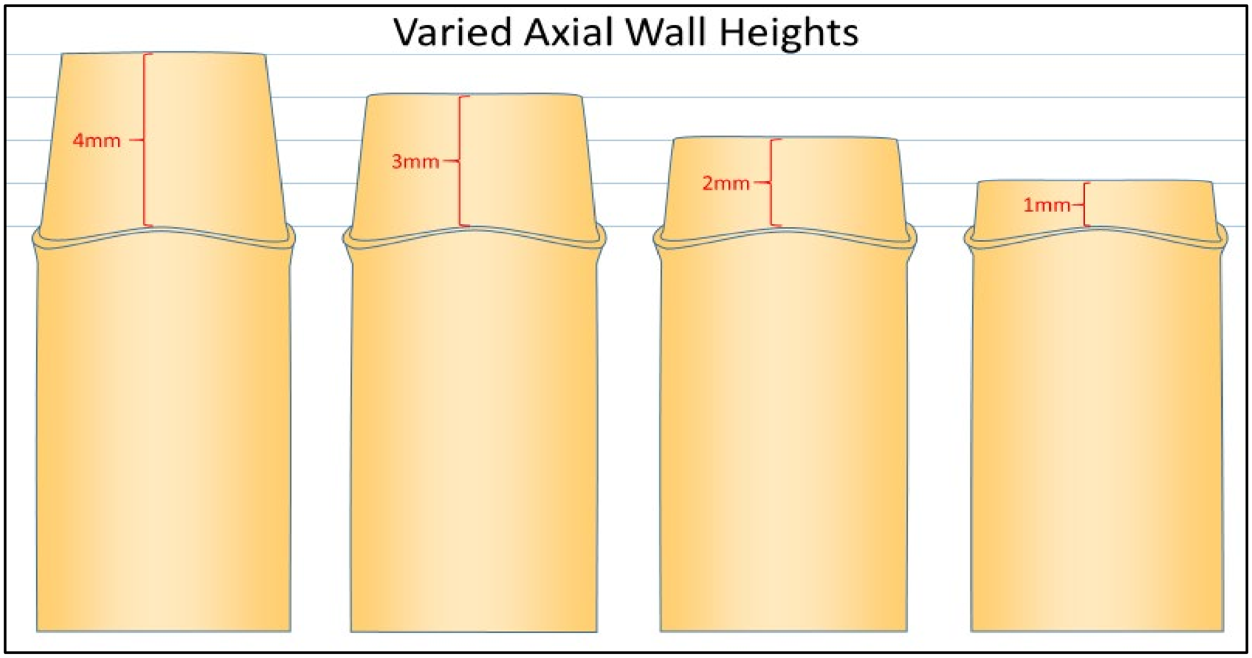


Figure 1. Varied axial wall heights of 4mm, 3mm, 2mm, and 1mm

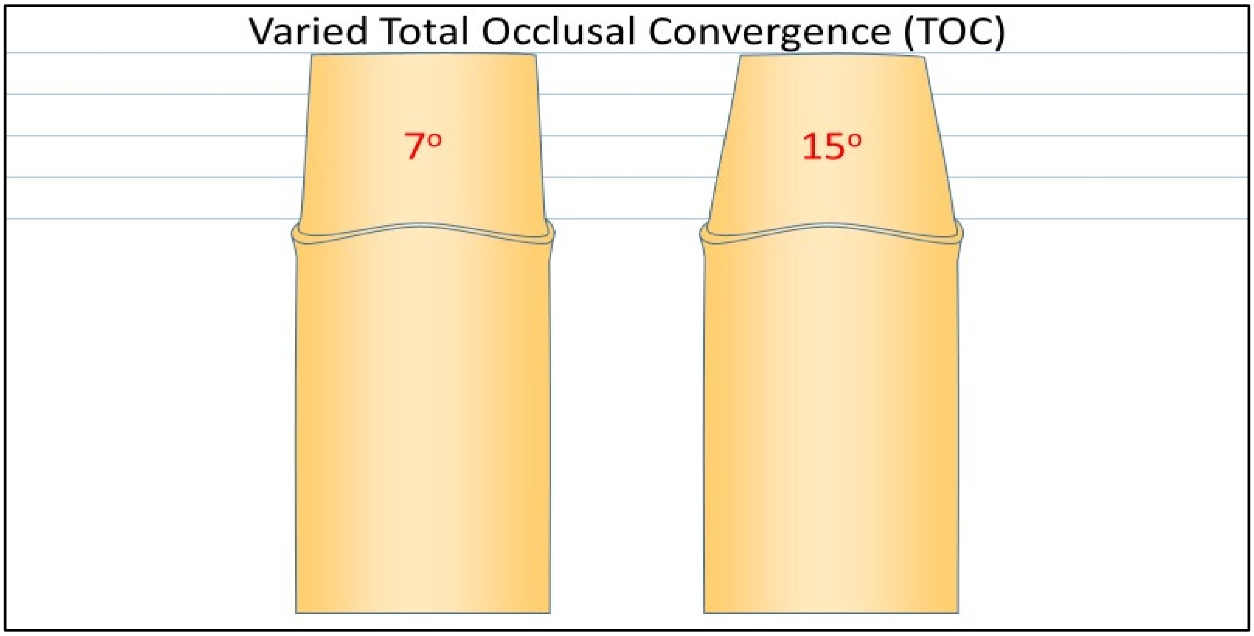


Figure 2. *Varied total occlusal convergence of 7° and 15°*

Each abutment had a corresponding 4Y-TZP zirconia (iMILL Zr, Imagine USA, Fullerton, CA) crown fabricated [Figure 3]. Crowns were designed using Freeform Plus (3D Systems, Rock Hill, SC) CAD software with a uniform cement space of 80 micrometers and an occlusal surface angled at 45 degrees to the long axis of the prosthesis. Each crown had an axial wall thickness of 1.5 mm.

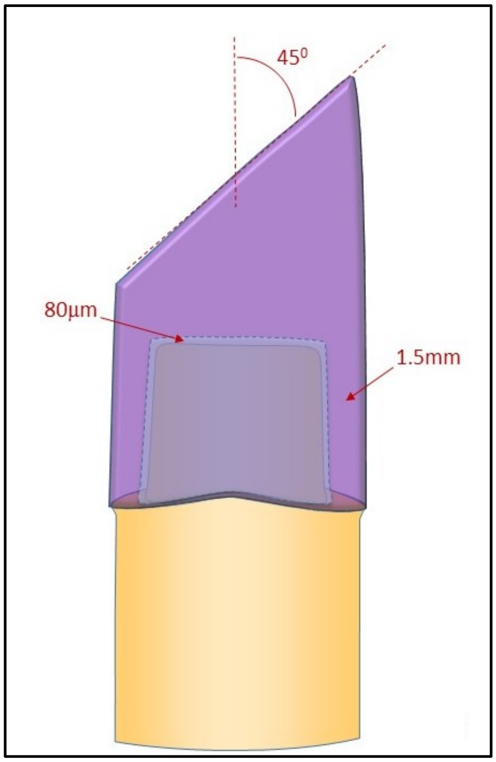


Figure 3. *Crown design*

Each crown and abutment were prepared for adhesive bonding by air abrasion with alumina oxide powder (50 microns) at 20-30 psi to the intaglio surface of crown and cameo surface of abutment, followed by ultrasonic cleaning, then dried with compressed, oil free air at 30 psi for 10 seconds. Next, ClearFil

Ceramic Primer Plus (Kurary America, Inc., New York, NY) was applied to each aforementioned surface per manufacturer instructions and allowed to react for 60 seconds, then dispersed with a mild stream of compressed, filtered, oil free air at 30 PSI for 2 seconds. Subsequently, Panavia V5 (Kurary America, Inc., New York, NY) adhesive cement was applied to the intaglio surface of the crown, the crown was placed on the abutment and seated, using a 3D-printed resin crown seating index with 10 pounds of pressure for 30 minutes [Figures 4, 5, & 6].

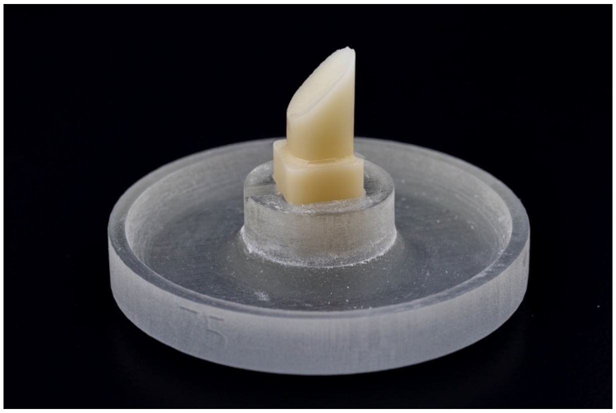


Figure 4. *Crown seating index base*

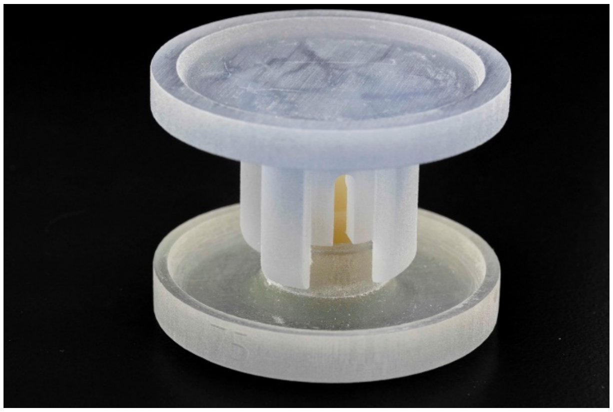


Figure 5. *Crown seating index top*

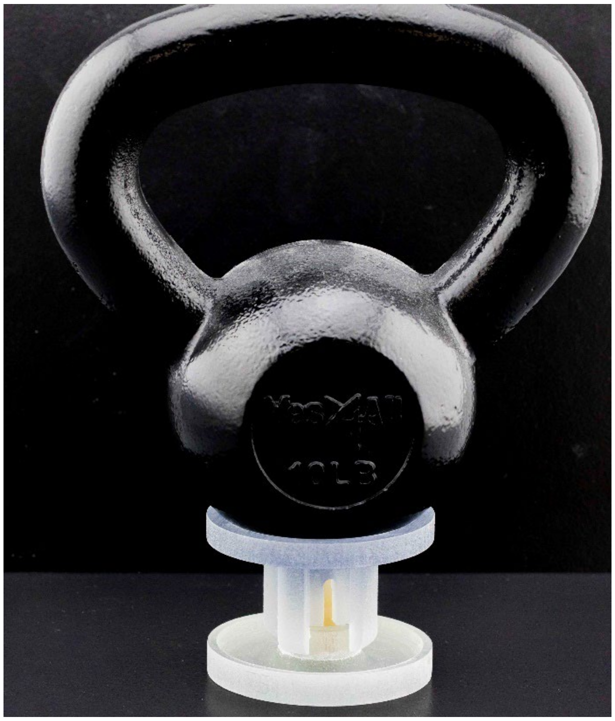


Figure 6. *Crown seating index with 10-pound weight*

Following cementation, samples were stored at 37ºC in 100% humidity for 24 hours, then thermocycled for 500 cycles in accordance with ISO/TS 11405 (Technical specification, 2003) standard for intermediate aging protocol prior to failure testing. Each 4Y-TZP abutment/crown sample was inserted into the testing apparatus: a custom-milled CoCr abutment holder bolted to the plate of an Industrial Series Instron Universal Testing

System (Instron, Norwood, MA). Compressive force, advanced at one millimeter per minute, was applied to the flat surface of the crown, 45 degrees to the long axis of the sample [Figure 7], until failure was achieved. Failure modes were recorded as debond, fracture of the crown. The mode and load at which failure occurred was recorded.

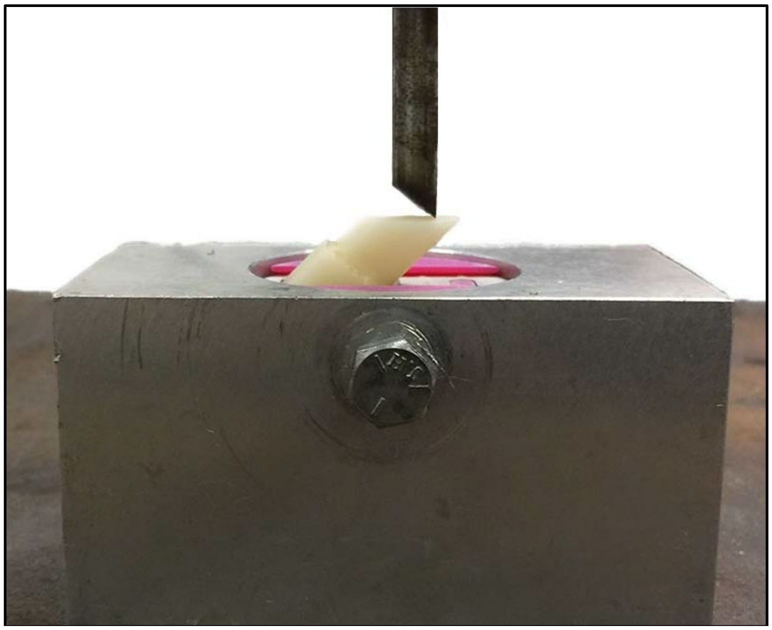


Figure 7. *Instron testing assembly*

The sample size of 10 per group provided 80% power to detect the following moderate effect sizes: 0.32 or approximately 0.64 standard deviations difference between means for the main factor of TOC (2 levels), and 0.38 or approximately 0.76 standard deviations difference among means for the main factor of AWH (4 levels). Interaction term was tested with a two-way ANOVA at the alpha level of 0.05 (NCSS PASS 2012). Post hoc testing was accomplished by using one-way ANOVA tests and Tukey's HSD tests on each AWH group.

RESULTS

Study samples were evaluated and recorded for the mode of failure. The two categories of failure were identified as 1) debond or 2) fracture of the crown. The total of 64 samples debonded crowns from their respective abutments. The rest of 16 samples failed due to fracturing of crowns prior to debonding [Table 1]. 7° TOC groups had higher number of fractured crowns compare to 15° TOC groups.

Sample Group	Dislodged Crowns	Fractured Crowns
1mm x 7°	10	0
2mm x 7°	10	0
3mm x 7°	6	4
4mm x 7°	0	10
1mm x 15°	10	0
2mm x 15°	10	0
3mm x 15°	10	0
4mm x 15°	8	2
Total	**64**	**16**

Table 1. *Mode of Failure*

The data for load at failure for eight different groups is summarized on Table 2. The study data was imported into SPSS computer software to calculate the minimum, median, maximum, mean and standard deviation for each test group. Mean and standard deviations of the load at failure were calculated [Table 3 and Table 4].

Load at Failure [N]								
	1mm x 7°	2mm x 7°	3mm x 7°	4mm x 7°	1mm x 15°	2mm x 15°	3mm x 15°	4mm x 15°
1	353.93	339.73	498.35	1005.37	270.72	142.82	653.03	489.52
2	565.96	521.95	1369.90	1194.14	311.17	514.37	565.93	492.41
3	584.71	444.13	1374.65	1156.08	1511.73	273.04	708.40	972.30
4	214.36	595.01	1239.47	1001.53	702.20	364.34	727.11	788.22
5	480.23	584.34	1364.50	1302.06	347.00	610.27	846.66	486.05
6	245.69	903.27	726.35	1028.81	131.70	491.12	718.21	816.68
7	460.76	1561.00	1038.49	1309.18	539.27	99.36	370.64	713.66
8	1452.34	771.30	1199.19	485.69	300.57	352.18	1019.33	559.91
9	1429.21	1017.58	543.59	1167.94	1788.04	624.45	804.63	816.21
10	1322.24	608.10	637.41	1291.80	358.19	440.66	964.44	803.29

Table 2. Load at Failure (N)

Sample Group	Mean Load at Break (N)	Standard Deviation (N)
1mm x 7°	710.94	492.45
2mm x 7°	734.64	355.34
3mm x 7°	999.19	361.30
4mm x 7°	1094.26	244.67
1mm x 15°	626.06	565.03
2mm x 15°	391.26	180.45
3mm x 15°	737.84	188.51
4mm x 15°	693.82	173.95

Table 3. Mean load [N] at failure by sample group

Sample Group	Mean Load at Break(N)	Standard Deviation (N)
1mm	668.5	517.68
2mm	562.95	325.98
3mm	868.52	310.88
4mm	894.04	291.35
7°	884.76	396.46
15°	612.25	338.67
TOTAL	**748.5**	**391.17**

Table 4. Mean load [N] at failure by AWH and TOC

Two-way ANOVA and one-way ANOVA were employed to determine whether any statistically significant difference existed among the tested groups, followed by Tukey's Honest Significant Difference test to determine significance of differences observed [Table 5].

	7°	15°	Total
1mm	710.94	626.06	668.50
2mm	734.64^{a}	391.26^{b}	562.95
3mm	999.19^{c}	737.84^{d}	868.52
4mm	1094.26^{e}	693.82^{f}	894.04
Total	884.76^{A}	612.25^{B}	

***Table 5**. Results of Post Hoc Analysis*

Different capital letters ($^{A, B}$) indicate statistically significant difference between TOC groups but no difference within TOC groups.

Different lower case letters ($^{a, b/ c,d/ e,f}$) indicate statistically significant difference within same AWH group (2mm,3mm and 4mm).

The results indicate that the overall 7° TOC groups had the mean load of failure at 884.76N, which is statistically higher than 15° TOC overall group, which had the mean load of failure at 612.25N. Within the 7° and 15° TOC groups, there was no statistically significant difference among different AWH's. For the 1mm AWH groups, there was no difference between 7° or 15° TOC; however, statistically significant difference between 7° and 15° TOC were found for 2mm, 3mm, and 4mm AWH groups.

DISCUSSION

The purpose of this study was to determine the effect of AWH and degree of TOC on the resistance to dislodgement of the milled 4Y-TZP zirconia crowns adhesively bonded to milled 4Y-TZP zirconia custom implant abutments.

The key factors to focus on this study are the mode of failure and the amount of force required to result in the failure. The large portion (80%) of the study samples failed due to debonding of specimens rather than fracturing. 14/16 (87.5%) fractured ceramic happened to the 7° TOC groups. Interestingly, all of the test groups failed at loads above the average human's maximum biting force (mean = 354N) (Takaki et al. 2014). These results reiterate, within the parameters of this in vitro study, adhesively bonding 4Y-TZP zirconia crowns to 4Y-TZP zirconia implant abutments using resin cement has adequate strength to withstand dislodging forces in oral environment if TOC is less than 15° and has at least 3mm of AWH.

For qualitative analysis of failure mode, dislodgement of crowns predominated. The only group that had a higher number of fracture than dislodgement was 4mm AWH x 7 degrees TOC. Because 7 degrees TOC was statistically significantly different than 15 degrees TOC, and because this difference was significant even with 4mm AWH, it stands to reason that to minimize the chance of crown dislodgement, a 4mm AWH with 7 degrees TOC would function best clinically for implant abutment and crown fabricated with 4Y-TZP

This in vitro study was design to create the most unfavorable condition that could be faced in clinical setting. Forces beyond maximum human mastication were applied at 45 degrees to the long axis of the study samples with a lever arm approximating 14mm from the point of rotation to simulate unpresented condition in vivo. Indeed, it is rare to find a situation where the available restorative space only allows 1 mm of AWH with 14mm tall crown. Therefore, the conditions created for this in vitro study exceed the rare condition that can be faced in vivo.

One drawback of this study model was not making the crown height adjusted as the AWH changed in length. By keeping the crown height consistent at 14mm, it introduced an unwanted cofounding factor to the study. The unforeseen added variable may have potential effects on force that dislodged crowns from abutments. As the AWH shortens, the crown height should have been decreased by the same length to keep the variables only to AWH and TOC.

The overall results on this in vitro study suggested that there were no significant differences among the AWH groups but demonstrated significant differences between TOC groups. The study results follow traditional principles of retention and resistance form for TOC but failed to find correlation in minimal AWH guideline. As the AWH increased, the study failed to demonstrate the statistically increase in load at failure. However, with narrower TOC, the load at failure were significantly higher in ≥2mm AWH groups.

Similar to many in vitro studies, it is infeasible to account for all of the factors, such as load frequency, vector, duration, and distribution that could potentially have impacts on restoration failure. When looking at the extent of deviation for 1mm AWH groups, it is noticeably high compare to rest of the groups. In order to have more reliable and accurate understanding of how the AWH plays role in retention and resistance, larger sample size is needed to decrease the potential errors with the study. In addition, more research is necessary to further investigate the mechanisms of failure of 4Y-TZP zirconia crowns bonded to 4Y-TZP zirconia implant supported abutments.

CONCLUSION

Findings from this in vitro study suggests that a milled 4Y-TZP zirconia crown adhesively bonded to a milled 4Y-TZP zirconia custom implant abutment can withstand the dislodging force when the abutment has at least 3mm of AWH and less than 15 degrees of TOC. All eight sample groups had mean load of failure greater than the human's maximum biting force and mostly remained bonded to respective crowns and abutments. There was statistically significant difference in the amount of force required to dislodge milled 4Y-TZP zirconia crowns bonded to milled 4Y-TZP zirconia abutments when the TOC of the abutment varies but not among different AWH groups. The TOC plays crucial role in resisting the dislodging force of 4Y-TZP zirconia crown adhesively bonded to 4Y-TZP zirconia abutment.

AKNOWLEDGMENTS

Sincere appreciation is expressed to the following individuals of the 59th Medical Wing, JBSA-Lackland, TX, for their assistance with this project: **Mr. James Pizzini**, Biomedical Engineer and Stereolithographer, Air Force Postgraduate Dental School (AFPDS), for design and fabrication of various iterations of milled and 3D-printed objects used in this project; **Mr. Paul Barnicott**, Deputy Director, and **Ms. Tammie Auton**, Budget/Supply Technician, Clinical Investigations & Research Support (CIRS), for procurement of funding and supplies; **Mr. Neal**

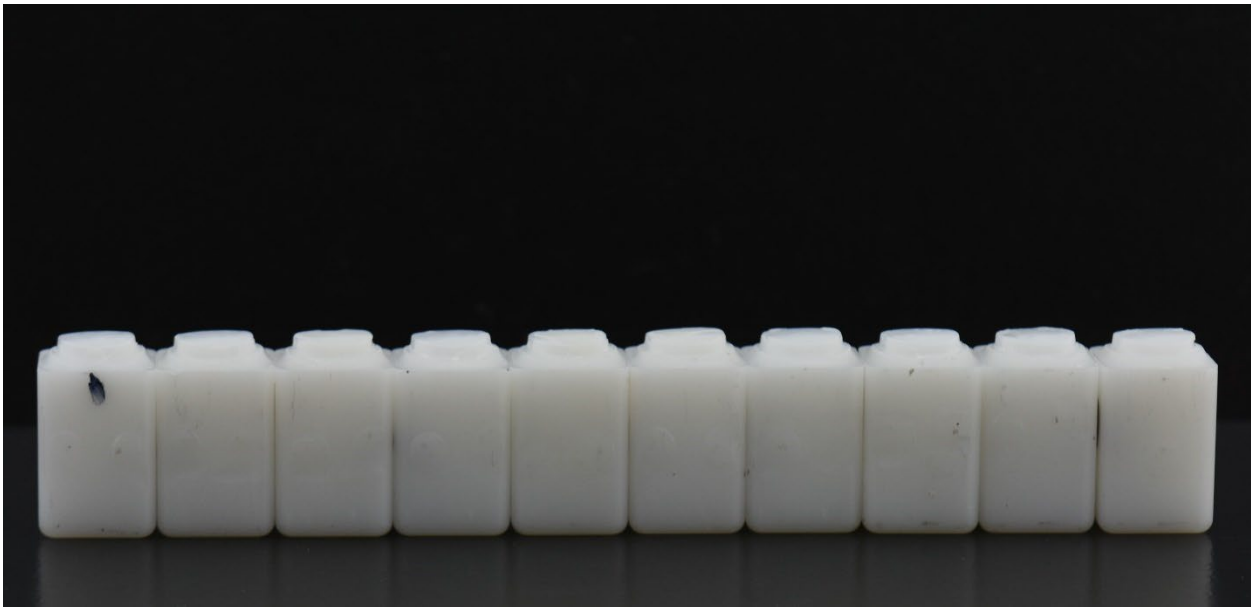
Demazure, Director of Sales, Imagine USA, and his team for coordination and milling of the ceramic crowns and abutments; **Dr. Kraig Vandewalle**, Director of Dental Research, AFPDS, for instruction on research design and sample preparation; **Mr. Daniel Sellers**, Biological Laboratory Science Technician, CIRS, for management of the Instron machine and data acquisition; **Dr. Anneke Bush**, Clinical Research Administrator, CIRS, for statistical analyses of the research data; **Dr. Cade Salmon**, Prosthodontics Program Director, AFPDS, for research mentorship and project oversight; **Dr. Troy Decker, Dr. Joshua Nardone, Dr. Paul Lee and Dr. Jens Nelson**, Prosthodontics Residents, AFPDS, for coordination and partnership through the entirety of this project.

DISCLOSURES

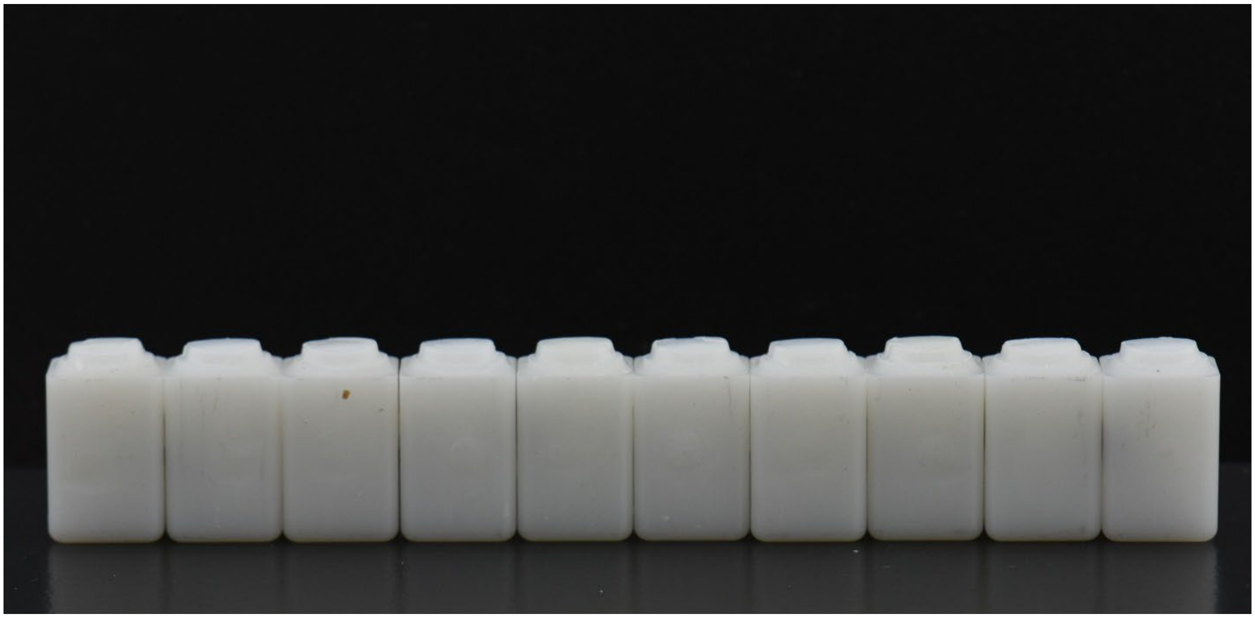
The opinions or assertions contained herein are the private ones of the author and are not to be construed as official or reflecting the view of the Uniformed Services University of the Health Sciences, the United States Air Force, the Department of Defense, or the United States Government. The author does not have any financial interest in any commercial products or services that are discussed in this publication.

APPENDIX 1 – Photos of sample groups after load failure testing

1mm x 7°



1mm x 15°



2mm x 7°

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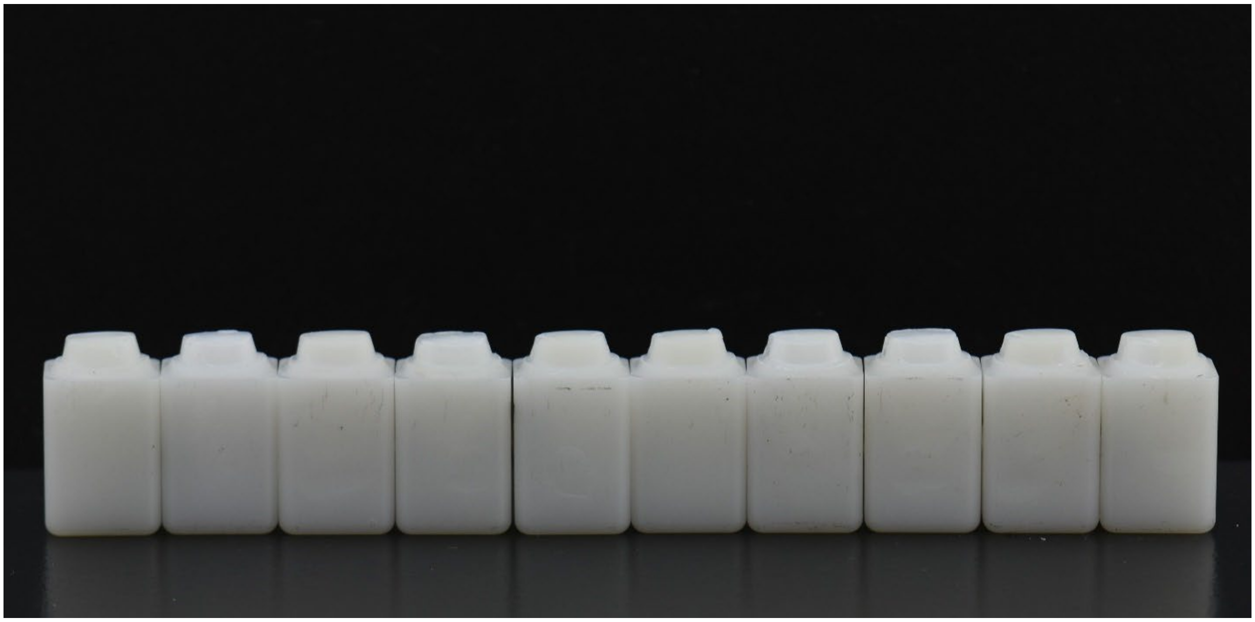

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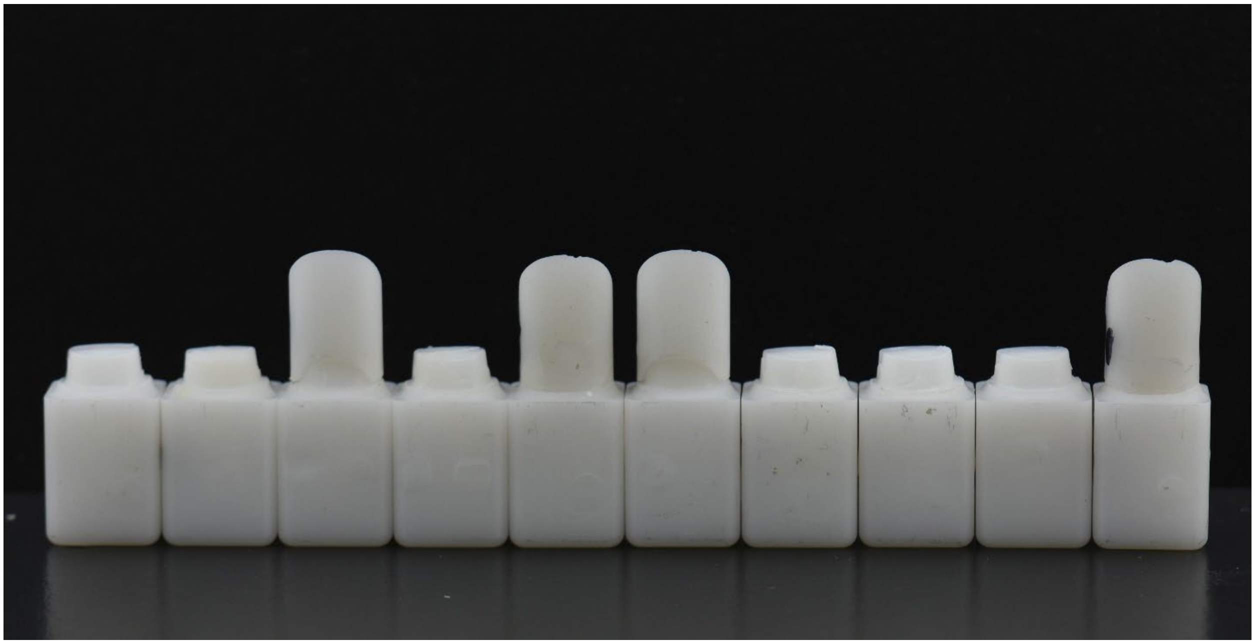

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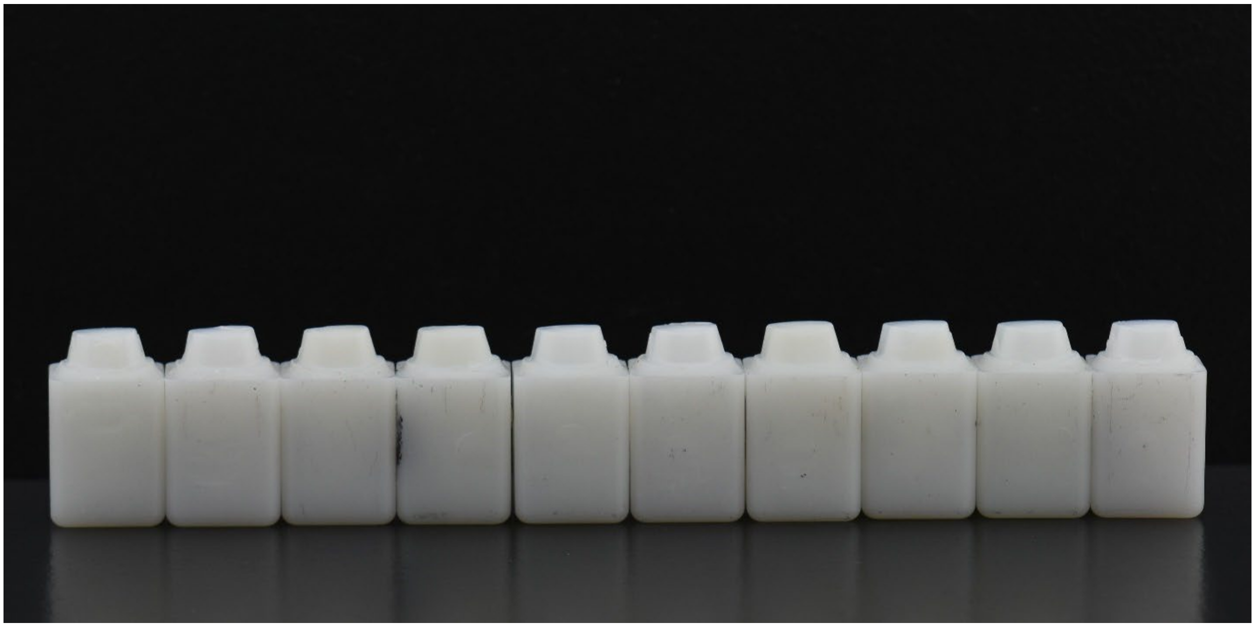

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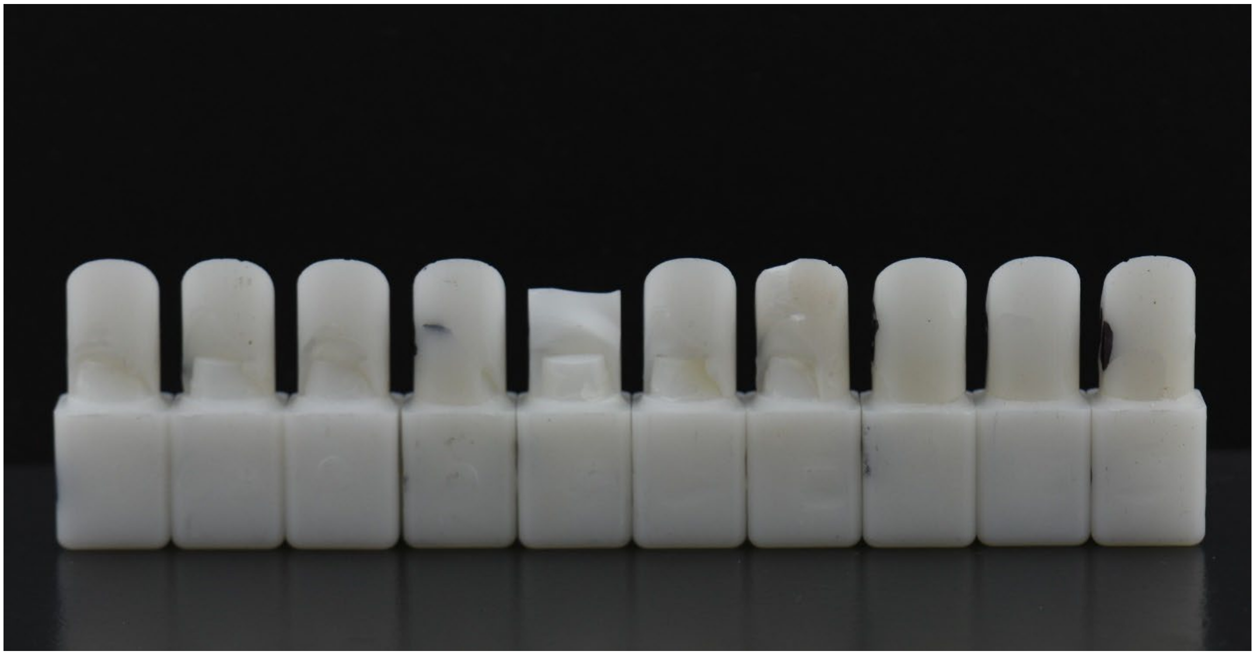

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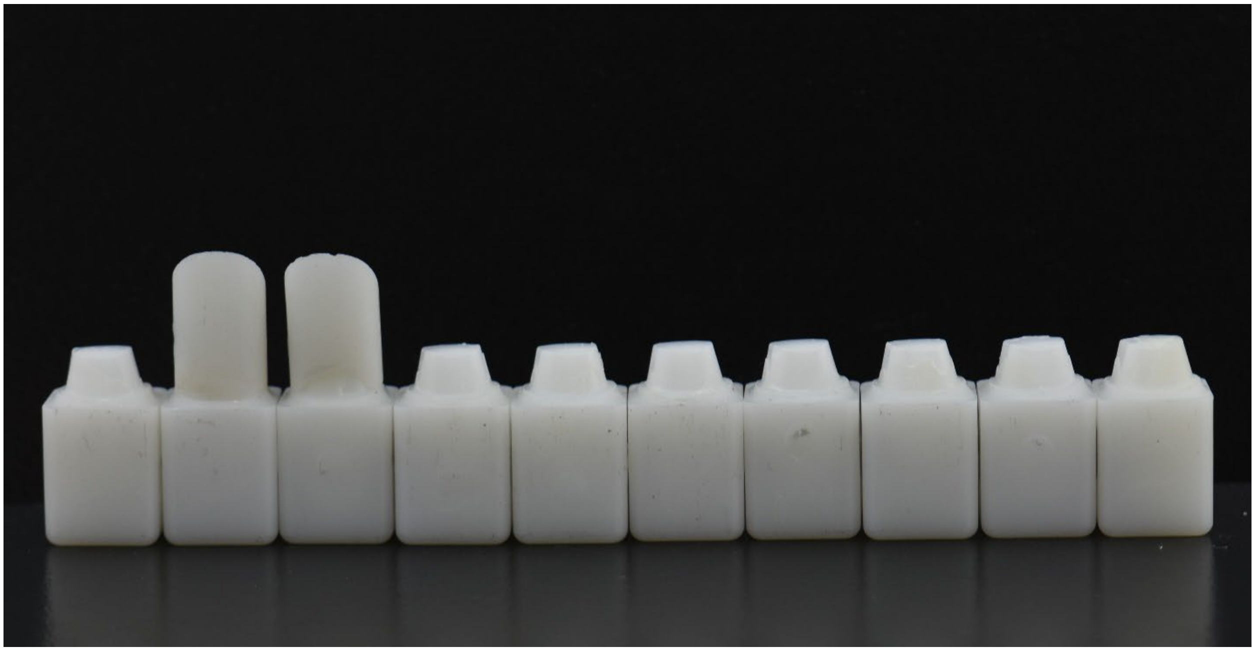

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