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# UNIFORMED SERVICES UNIVERSITY OF THE HEALTH SCIENCES

POSTGRADUATE DENTAL COLLEGE  
SOUTHERN REGION OFFICE  
2787 WINFIELD SCOTT ROAD, SUITE 220  
JBSA FORT SAM HOUSTON, TEXAS 78234-7510  
<https://www.usuhs.edu/pdc>



## THESIS APPROVAL PAGE FOR MASTER OF SCIENCE IN ORAL BIOLOGY

Title of Thesis:

Name of Candidate:

Master of Science Degree

THESIS/MANUSCRIPT APPROVED:

DATE:

\_\_\_\_\_  
Dr. Wesley Shute  
DEPARTMENT OF PROSTHODONTICS, USUHS Postgraduate Dental School  
Committee Chairperson

\_\_\_\_\_

\_\_\_\_\_  
Dr. Matthew Checketts  
DEPARTMENT OF PROSTHODONTICS, USUHS Postgraduate Dental School  
Committee Member

\_\_\_\_\_

\_\_\_\_\_  
Dr. Hannah Colburn  
DEPARTMENT OF PROSTHODONTICS, USUHS Postgraduate Dental School  
Committee Member

\_\_\_\_\_

\_\_\_\_\_  
Dr. Sae-Eun Schlottko  
DEPARTMENT OF PROSTHODONTICS, USUHS Postgraduate Dental School  
Committee Member

\_\_\_\_\_

\_\_\_\_\_  
Dr. Aaron Harding  
DEPARTMENT OF PROSTHODONTICS, USUHS Postgraduate Dental School  
Program Director

\_\_\_\_\_

\_\_\_\_\_  
Dr. Cade Salmon  
DEPARTMENT OF PROSTHODONTICS, USUHS Postgraduate Dental School  
Department Chair

\_\_\_\_\_

**Effect of Axial Wall Height and Total Occlusal Convergence of 5Y-ZP Zirconia  
Implant Abutments on the Retention of Adhesively Bonded 5Y-ZP Zirconia Crowns**



By  
Maj Paul T. Lee, DDS  
Prosthodontics Resident, Air Force Postgraduate Dental School and Uniformed Services  
University of the Health Sciences Postgraduate Dental College

16 May 2021

Thesis Advisor:  
Lt Col Cade A. Salmon, DDS  
Prosthodontics Program Director, Air Force Postgraduate Dental School  
Associate Professor of Prosthodontics, Uniformed Services University of the Health Sciences  
Postgraduate Dental College

## TABLE OF CONTENTS

<a href="#"><u>ABSTRACT</u></a> .....	3
<a href="#"><u>INTRODUCTION</u></a> .....	4
<a href="#"><u>HYPOTHESIS</u></a> .....	10
<a href="#"><u>METHODS &amp; MATERIALS</u></a> .....	10
<i><a href="#"><u>Figure 1</u></a> - Varied axial wall heights</i> .....	10
<i><a href="#"><u>Figure 2</u></a> - Varied total occlusal convergence</i> .....	11
<i><a href="#"><u>Figure 3</u></a> - Crown design</i> .....	11
<i><a href="#"><u>Figures 4-6</u></a> - Crown seating index</i> .....	12
<i><a href="#"><u>Figure 7</u></a> - Instron testing assembly</i> .....	13
<a href="#"><u>RESULTS</u></a> .....	14
<i><a href="#"><u>Table 1</u></a> - Mode of failure</i> .....	13
<i><a href="#"><u>Table 2</u></a> - Load at failure point for each sample</i> .....	14
<i><a href="#"><u>Tables 3-4</u></a> - Mean load at failure</i> .....	14
<i><a href="#"><u>Table 5</u></a> – Results of Post Hoc Analysis</i> .....	15
<i><a href="#"><u>Table 6</u></a> – Two-way ANOVA tests of axial wall height and total occlusal convergence</i> ..	16
<i><a href="#"><u>Table 7</u></a> – One-way ANOVA of total occlusal convergence at a given axial wall height</i> .	16
<i><a href="#"><u>Tables 8-9</u></a> - Tukey HSD for total occlusal convergence</i> .....	16
<a href="#"><u>DISCUSSION</u></a> .....	16
<a href="#"><u>CONCLUSION</u></a> .....	19
<a href="#"><u>ACKNOWLEDGEMENTS</u></a> .....	19
<a href="#"><u>DISCLOSURES</u></a> .....	20
<a href="#"><u>APPENDIX 1</u></a> - Photos of sample groups after load failure testing .....	20
<a href="#"><u>LITERATURE CITED</u></a> .....	24

## **ABSTRACT**

**Statement of Problem:** Currently, no published data exists to provide clinical guidance on decisions relative to total occlusal convergence (TOC) and axial wall height (AWH) regarding a 5Y-ZP zirconia crown bonded to a zirconia abutment.

**Purpose:** The purpose of this study was to quantify the effect of total occlusal convergence and axial wall height on the resistance form of a milled 5Y-ZP zirconia crown adhesively bonded to a milled 5Y-ZP zirconia custom implant abutment.

**Materials and Methods:** Eight groups of ten 5Y-ZP zirconia (Dental Direkt CubeX<sup>2</sup> ML, Spenge, Germany) crown and 5Y-ZP zirconia abutment (Dental Direkt CubeX<sup>2</sup>, Spenge, Germany) pairs (n=10) were fabricated. Each group differed in AWH (H-4mm, H-3mm, H-2mm, H-1mm) and TOC (C-7°, C-15°) of the abutment and corresponding crown. 5Y-ZP zirconia crowns and abutments were air abraded with aluminum oxide (50 microns, 20-30psi, steam-cleaned) and adhesively bonded to each other using the Panavia V5 (Kuraray North America, Houston, TX) resin cement system. After cementation, samples were artificially aged with thermocycling (500 cycles, 5-55°C, dwelling time 30 seconds), mounted into the Instron Universal Testing Machine (Instron, Norwood, MA) and forces directed at 45° to the long axis of the sample were applied to failure (debonding or fracture). The mode of failure and the load at which failure occurred was recorded.

**Results:** 85% (68/80) of crowns debonded from their respective abutments. 15% (12/80) of crowns fractured. All fractured samples were from the C-7° group with 3mm and 4mm AWH. The load at failure follows the AWH, testing lowest in the H-1mm group and highest in the H-4mm group. Statistically significant difference of load at failure was found between C-7° and C-15° group, specifically within the H-2mm and H-3mm axial wall height groups ( $p < 0.05$ ). In C-7°

group, the force required to dislodge H-3mm and H-4mm groups was statistically significantly higher than samples from the H-1mm group. Within the C-15° group, H-4mm group showed statistically significantly higher force required to dislodge as compared to other groups.

**Conclusions:** Results of this *in vitro* study indicate that, when bonded with resin cement, milled 5Y-ZP zirconia crowns will dislodge from milled 5Y-ZP zirconia implant abutments due to lack of conventional resistance form in regard of AWH or TOC. At least 4mm AWH with 7° TOC or 15° TOC of custom implant abutments are recommended to resist crown debonding within the average maximum biting forces.

## **CLINICAL IMPLICATIONS**

When using a split file technique to fabricate 5Y-ZP zirconia single-unit implant-supported restorations, an AWH of  $\geq 4$ mm with a TOC of 7° or 15° will resist dislodging forces when the crown and abutment were bonded with resin cement system.

## **INTRODUCTION**

Trauma, disease and developmental conditions can all lead to missing teeth. Osseointegrated dental implants provide the means to replace missing teeth with an esthetic outcome and functionality that is similar to the natural tooth (Kashbour, Rousseau, Ellis, & Thomason, 2015). Implant therapy is frequently employed for single-tooth restoration. Single-tooth implant restorations can be divided into implant-supported or abutment-supported prosthesis. These types of restorations are also known as screw-retained or cement-retained restorations respectively.

Cement-retained, or abutment-supported, implant restorations consist of an abutment that is attached to the implant with a dental crown cemented or bonded to the abutment. Cement-

retained implant restorations are often chosen for their ease and convenience of delivery, or to help restore an implant that has been placed in a non-centralized or off-angled position relative to the restorative crown. The abutment can be pre-fabricated or custom made. Several materials are available for use in the fabrication of both the abutment and the crown. Various luting and adhesive agents are also available to cement implant crowns to abutments. Careful attention must be given to many elements of crown/abutment design in order to ensure the long-term success of this type of restoration.

The ability of a crown to remain attached to an abutment is a primary concern in the design of a successful crown/abutment combination. This attachment is dependent on both the adhesion that occurs between the crown and abutment, as well as design parameters of the abutment that enhance the overall ability to resist dislodgement of the crown. These design parameters are known as the resistance-form of the abutment.

Various cementation modalities are used to keep crowns attached to abutments. Many abutment materials such as gold and titanium cannot be readily bonded. For that reason many common dental cements act as luting agents and do not actually provide a chemical bond. Principles of resistance-form create a geometric relationship between the crown and abutment that resists forces that would otherwise dislodge the crown from the abutment. Total occlusal convergence (TOC) and axial wall height (AWH) are two of the crucial factors affecting the resistance form of the abutment or tooth preparation and their ability to retain the veneering structure from dislodgement. TOC is the angle between two opposing axial surfaces and AWH is the occluso-cervical dimension of the prepared surface. Maximal tensile strength for crown retention has been shown to exist for TOC between 6° and 12° in the laboratory setting (Wilson & Chan, 1994). Sixteen degrees has been considered clinically reasonable while providing

sufficient tipping resistance of cemented crown (Dodge, Weed, Baez, & Buchanan, 1985).

Parker et al evaluated an average preparation height-to-base ratio and determined the maximum TOC with different AWH for adequate resistance to dislodgement (Parker, Calverley, Gardner, & Gunderson, 1993). Goodacre et al summarized literature from the past 50 years and concluded that TOC should be between 10° to 20° with a minimal 3mm AWH for anterior teeth and premolars and 4mm for molars (Goodacre et al., 2001). Not all restorative situations, however, lend themselves readily to creating ideal resistance form.

With implant restorations and available restorative space, it is not always possible to achieve ideal resistance form, especially relative to AWH. According to Misch, the ideal crown height space between 8 and 12 mm is required for biologic width, emergence profile, abutment height, and occlusal materials for cement-retained restorations to have a predictable outcome (Misch et al., 2005). When available crown height space does not allow for the recommended 3 mm or 4 mm of AWH, the restoration design team is forced to either accept the risk of less-than-ideal resistance form or abandon the cement-retained restoration and choose a purely screw-retained restoration design. In this situation, the question often arises, “Could bonding the crown to the abutment compensate for the lack of ideal resistance-form?” and, “If yes, to what extent?”

Studies have shown that less-than-ideal resistance form can be compensated for with adhesive bonding when crowns are bonded to underlying tooth structures. Several studies were conducted to evaluate the significance of AWH in fracture resistance involving CAD/CAM adhesively bonded, all ceramic full coverage restorations. Hoopes et al concluded that crowns bonded to molar preparations with 2-4mm of AWH demonstrated statistically similar failure loads, while crowns bonded to preparations with 0-1mm AWH failed at statistically significantly lower loads (Hoopes et al., 2018). Martin et al found similar results with crowns bonded to

premolar preparations with 2-3 mm AWH as compared to those with less than 2 mm (Martin, Harris, DuVall, Wajdowicz, & Roberts, 2018). Gillette and colleagues found no significant difference in failure stress resistance when crowns were bonded to premolar preparations having 1 mm, 2 mm, or 3 mm AWH and 10° TOC (Gillette et al., 2016). Miller recommended that bonded crowns need a minimum of 2 mm of AWH and 20° TOC (Miller et al., 2018). Another systematic review by Morimoto et al showed that the improved resin cements may allow adhesive bonding of ceramic onlays to natural tooth with less than ideal AWH and still generate promising long-term in-vivo survival rates at 5 and 10 years of 92-95% and 91%, respectively (Morimoto, Rebello de Sampaio, Braga, Sesma, & Ozcan, 2016). Significant enhancement of ceramic materials and adhesive agents are changing the treatment workflow.

In addition to bonding to tooth structure, resin cements and bonding systems can be used to bond crowns to abutments made of certain materials. Resin cements can bond chemically to silanated ceramic (Diaz-Arnold, Vargas, & Haselton, 1999). With the application of phosphate-containing monomers such as MDP, resin cements can bond chemically to the oxides in Zirconium dioxide, which is commonly used to fabricate both dental abutments and crowns (De-Paula et al., 2017). With this ability to bond resin cement to many different materials, it becomes important to know to what extent bonding crowns to abutments will help to compensate for less than ideal dimensions of resistance form.

Zirconia is a metastable ceramic with monoclinic, tetragonal, and cubic crystalline phases. Pure zirconia is stable in its monoclinic phases in room temperature, and different amounts of yttria are used to stabilize the zirconia in tetragonal or cubic crystalline phases.

Yttrium-stabilized zirconia is a polycrystalline ceramic extensively used in restorative dentistry with its favorable mechanical properties compared to other ceramics, such as high

flexural strength, fracture resistance, and fracture toughness (Özcan and Bernasconi 2015). 3 mol% yttria-stabilized tetragonal zirconia polycrystal (3Y-TZP) contains tetragonal zirconia that responds to crack formation with transformation toughening, in which a transformation zone is generated with volumetric changes to prevent the crack from further propagation (Kelly and Denry 2008). The disadvantage of 3Y-TZP is lack of translucency to mimic natural teeth. A partially stabilized zirconia with increased yttria content, 5 mol % yttria-stabilized zirconia polycrystal (5Y-ZP), has been introduced recently as an alternative for anterior restorations requiring increased translucency. It has higher cubic phase zirconia (>50%) that reduces light scattering and improves translucency, which comes at the cost of decreased mechanical properties (Kwon et al 2018). The mechanical characteristics and dimensional requirements of 5Y-ZP are comparable to lithium disilicate material, with higher wear resistance compared to lithium disilicate or enamel (Rosentritt et al. 2020). The bond strengths obtained for 5Y-ZP are similar to those obtained for the 3Y-TZP using the same bonding strategies (Chen et al. 2020). 5Y-ZP is a viable material choice for the restoration of anterior implants.

This study will examine the effects of varying AWH and TOC of 5Y-ZP custom abutments on the bond strength of 5Y-ZP crowns bonded with resin cement.

## **HYPOTHESIS**

**Null hypothesis:** There is no statistically significant difference in the amount of force required to dislodge 5Y-ZP zirconia crowns bonded to 5Y-ZP 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 5Y-ZP zirconia crowns bonded to 5Y-ZP 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 5Y-ZP zirconia (Dental Direkt CubeX<sup>2</sup>, Spenge, Germany). 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.

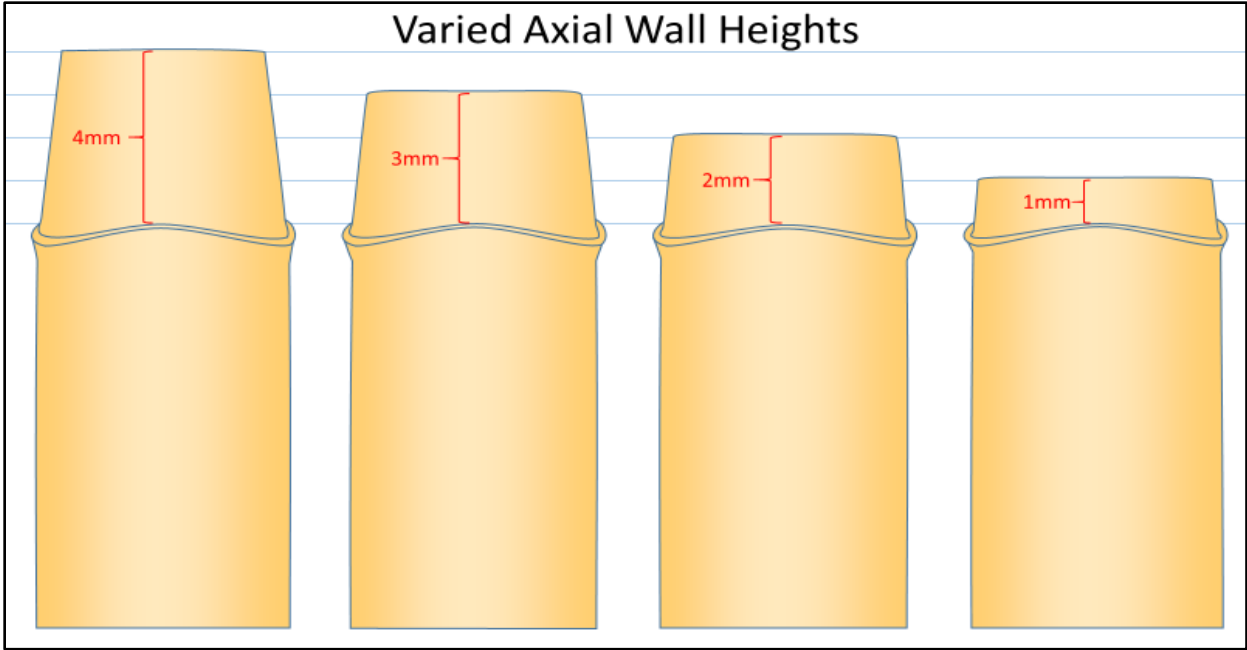


Figure 2. Varied axial wall heights of 4mm, 3mm, 2mm, and 1mm

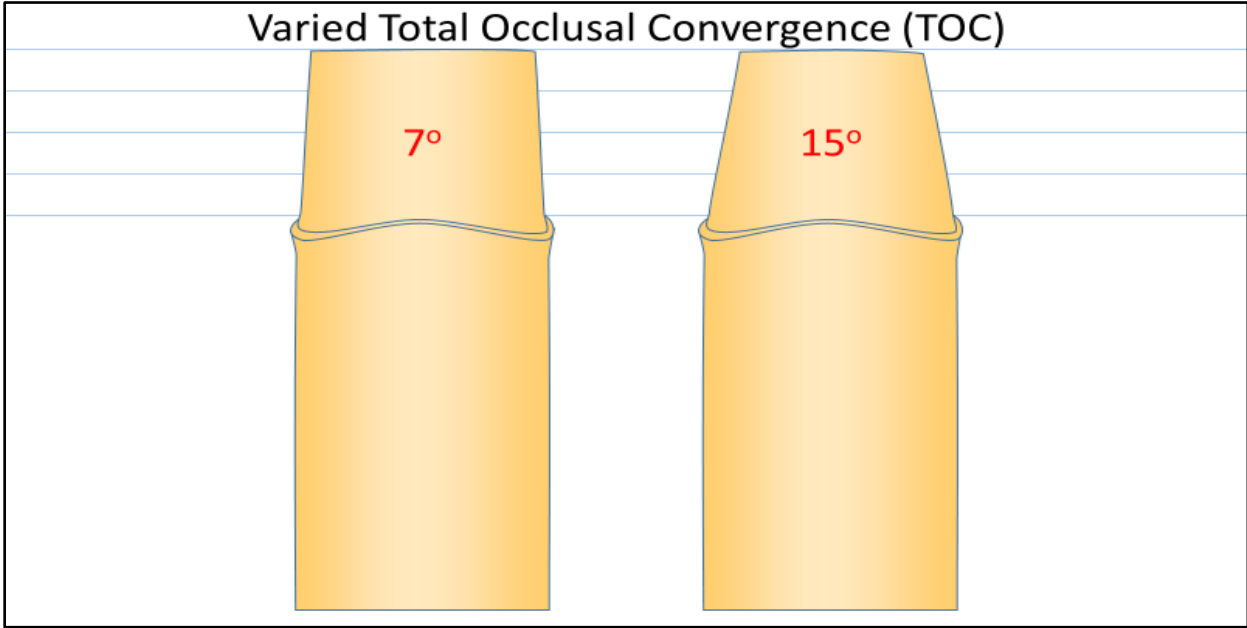
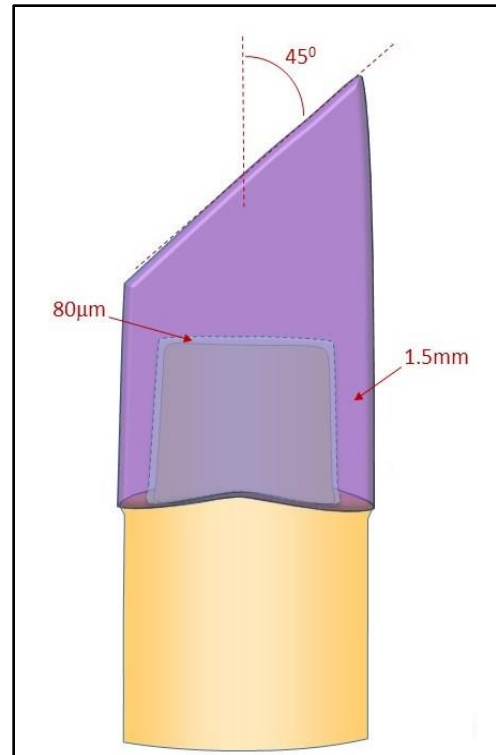


Figure 1. Varied total occlusal convergence of 7° and 15°

Each abutment had a corresponding 5Y-ZP zirconia ((Dental Direkt CubeX<sup>2</sup> ML, Spenge, Germany) 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.

Each crown and abutment was 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 steam cleaning, then dried with compressed, oil free air at 30 psi for 10 seconds. Next, ClearFil Ceramic Primer Plus (Kuraray 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 (Kuraray America, Inc., New York, NY) adhesive cement



**Figure 3. Crown design**

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 (Mannix Timer) [Figures 4, 5, & 6].

Following cementation, samples were stored at 37°C 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 5Y-ZP 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 included debonding or fracture of the crown, abutment, or both. The mode and load at which failure occurred was recorded.

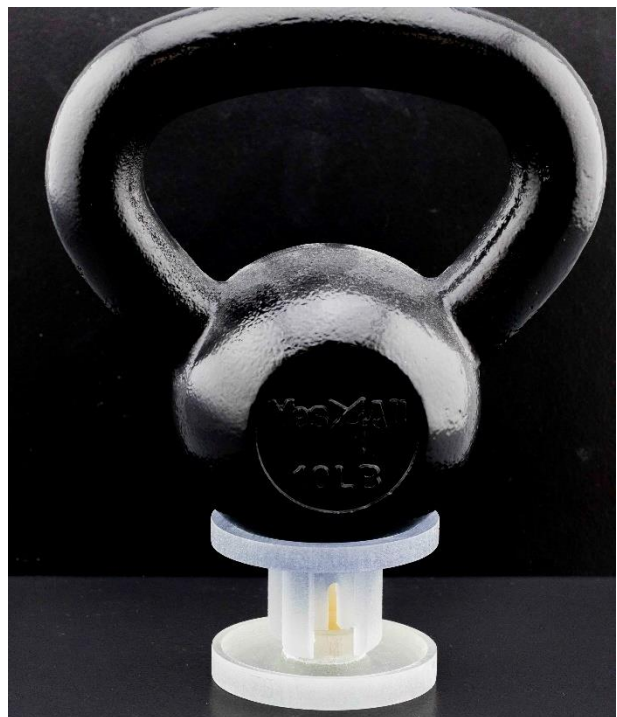
The sample size of 10 per group provided 80% power to detect the following moderate effect sizes: 0.32 or approximately 0.64 standard deviations difference between



*Figure 4. Crown seating index base*

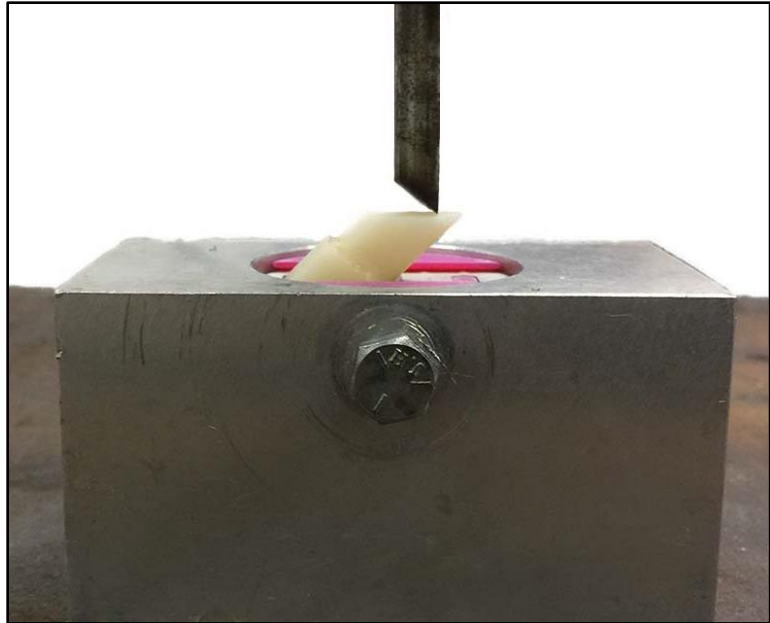


*Figure 5. Crown seating index top*



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

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



*Figure 7. Instron testing assembly*

ANOVA tests and Tukey’s HSD tests on each AWH groups.

## **RESULTS**

The mode of failure was evaluated and recorded for each sample, the two primary categories being 1) the crown debonded or 2) the crown fractured. 85% of the crowns (68/80) debonded from their respective abutments and 15% of the crowns (12/80) fractured prior debonding [Table 1].

<b>Sample Group</b>	<b>Dislodged Crowns</b>	<b>Fractured Samples</b>
1mm x 7°	10	0
1mm x 15°	10	0
2mm x 7°	10	0
2mm x 15°	10	0
3mm x 7°	6	4
3mm x 15°	10	0
4mm x 7°	2	8
4mm x 15°	10	0
<b>Total</b>	<b>68 (85%)</b>	<b>12 (15%)</b>

*Table 1. Mode of failure*

SPSS computer software was used to calculate and tabulate the data. The load at failure for each test group are summarized [Table 2]. Minimum, median, and maximum load at failure are demonstrated [Table 3 and Table 4]. Two-way ANOVA and one-way ANOVA were used to determine whether significant differences existed among the study groups (i.e. AWH and degree of TOC), followed by Tukey pairwise multiple comparisons at 95% confidence interval, which were performed to determine which AWH group at a given TOC group significantly differed from the other [Table 5].

Load at Failure [N]				
	1mm x 7°	2mm x 7°	3mm x 7°	4mm x 7°
1	381.5	366.7	488.5	846.9
2	654.5	809.8	459.8	807.0
3	297.9	722.3	658.6	1080.7
4	253.2	580.1	305.0	582.2
5	193.6	302.3	966.7	498.1
6	214.6	360.7	638.1	993.0
7	422.2	446.4	577.5	624.3
8	146.1	521.1	346.3	723.2
9	228.4	825.9	1057.8	962.2
10	134.6	363.7	921.0	621.0
	1mm x 15°	2mm x 15°	3mm x 15°	4mm x 15°
1	257.2	375.2	394.2	787.8
2	214.0	153.7	499.1	1023.9
3	201.8	345.7	481.4	751.5
4	305.1	343.7	397.7	973.3
5	131.6	303.7	475.4	546.5
6	220.2	199.7	403.4	546.8
7	137.2	279.6	438.2	776.3
8	202.6	424.2	303.4	556.1
9	372.4	407.2	428.2	565.4
10	323.9	374.1	468.3	915.3

*Table 2. Amount of load [N] at failure point for each sample*

Sample Group	Mean Load at Failure (N)	Standard Deviation (N)
1mm x 7°	292.66	157.65
1mm x 15°	236.60	78.34
2mm x 7°	529.90	196.42
2mm x 15°	320.68	87.99
3mm x 7°	641.93	262.12
3mm x 15°	428.93	57.80
4mm x 7°	773.86	195.83
4mm x 15°	744.29	185.11

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

Sample Group	Mean Load at Failure (N)	Standard Deviation (N)
1mm	264.63	27.84
2mm	425.29	34.03
3mm	535.43	42.44
4mm	759.08	42.61
7°	559.59	32.64
15°	432.63	17.94

**Table 4.** Mean load [N] at failure by axial wall height and TOC

	7°	15°	Total
1mm	292.66 <sup>1</sup>	236.60 <sup>3</sup>	264.63
2mm	529.90 <sup>a</sup>	320.68 <sup>3/4,b</sup>	425.29
3mm	641.93 <sup>2,c</sup>	428.93 <sup>4,d</sup>	535.43
4mm	773.86 <sup>2</sup>	744.29 <sup>5</sup>	759.08
Total	559.59	432.63	

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

Different numbers <sup>(1,2,3,4,5)</sup> indicate statistically significant difference between different AWH groups  
 Different lower case letters <sup>(a,b,c,d)</sup> indicate statistically significant difference between different TOC group

The results indicate

- Both AWH and TOC have statistically significant effects on the load of failure, and there is not an interaction between the two [Table 6].
- There is a significant difference between 7 TOC and 15 TOC when AWH was 2mm or 3mm, but not for 1mm or 4mm [Table 7].
- Within the 7 TOC group, there is statistically significant difference between different AWH's (3&4mm vs 1mm) [Table 8].
- Within the 15 TOC group, there is statistically significant difference between different AWH's (4mm vs 3&2mm vs 2&1mm) [Table 9].

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Axial Wall Height	2585902.327	3	861967.443	31.065	0.000
Total Occlusal Convergence	322389.528	1	322389.528	11.619	0.001
Axial Wall Height * Total Occlusal Convergence	143406.056	3	47802.019	1.723	0.170

*Table 6. Two-way ANOVA of axial wall height and total occlusal convergence*

Axial Wall Height	Type III Sum of Squares	df	Mean Square	F	Sig.
1mm	15713.618	1	15713.618	1.014	0.327
2mm	218865.042	1	218865.042	9.449	0.007
3mm	226845.000	1	226845.000	6.297	0.022
4mm	4371.925	1	4371.925	0.120	0.733

*Table 7. One-way ANOVA of total occlusal convergence at a given axial wall height*

Axial Wall Height	N	Subset 1	Subset 2
1	10	292.660	
2	10	529.900	529.900
3	10		641.930
4	10		773.860

*Table 8. Tukey HSD for 7° total occlusal convergence*

Axial Wall Height	N	Subset 1	Subset 2	Subset 3
1	10	236.600		
2	10	320.680	320.680	
3	10		428.930	
4	10			744.290

*Table 9. Tukey HSD for 15° total occlusal convergence*

## DISCUSSION

The purpose of this study was to quantify the effect that AWH and degree of TOC have on the resistance to dislodgement of milled 5Y-ZP zirconia crowns bonded to milled 5Y-ZP zirconia custom implant abutments. This data demonstrates that significant differences exist between different AWH and TOC groups. The null hypothesis was that there would be no statistically significant difference in the amount of force required to dislodge 5Y-ZP zirconia crowns bonded to 5Y-ZP zirconia custom implant abutments when the AWH of the abutments and the TOC of those axial walls varied. Therefore, the null hypothesis was rejected.

The most important factors to consider in the results of this study are the mode of failure and the mean load required for failure. Most of the samples failed due to debonding of the crowns (85%) rather than fractured (15%) [Table 1]. Considering the maximum bite force (mean = 354 N) generated in human mastication (Takaki *et al.*, 2014) and during sleep associated bruxism (mean = 415 N) (Nishigawa *et al.*, 2001), all groups except 4mm AWH groups would be at greater risk of debonding of the crowns given that the mean load at failure is < 415 N after consideration of standard deviation to account for predictability of the result. According to the data of this study, at least 4mm AWH with 7° or 15° TOC are required for the resin bonding of 5Y-ZP zirconia crowns to 5Y-ZP zirconia abutments to consistently resist dislodging forces typically produced in the oral environment.

This study was designed to simulate the most unfavorable condition *in vitro* in which a 5Y-ZP zirconia crown bonded to a 5Y-ZP zirconia implant-supported abutment could receive a load *in vivo*. Particularly, a load applied at 45 degrees to the long axis of the restoration with the lever arm (approximately 14mm from the point of rotation) to simulate the cusp height of what would be encountered clinically. In clinical situation, the cusp height is dictated by the occlusal reduction according to the desired restorative material and is commonly 1-4mm from the abutment height. Even in situations with limited restorative space, it is unlikely to have a 1mm tall abutment but required a 14mm tall crown, which further demonstrates that this study generates more extreme conditions than would likely be encountered *in vivo*.

Analysis of the data led our research team to a discussion focused on the large variability seen particularly in the shorter AWH groups. It was during this analysis and discussion that we realized that our design had inadvertently introduced a confounding variable. In an attempt to keep all factors unchanged, only varying the AWH, we had designed to keep the overall crown height

the same for all AWH groups. In doing this, however, we altered the cusp height. The change in this relationship effectively results in a longer lever-arm when force is applied, thereby varying the amount of force placed on the cusp. Clinically, an operator would never electively choose short AWH, rather it would be dictated by the available restorative space, thus a relative constant cusp height would exist in the clinical setting. This important discovery brings into question the validity of this study's data but is an important step in the search to answer the relevant clinical question. A constant cusp height should be used for consistent result if a similar study is performed.

The results of this *in vitro* investigation indicated that there were statistically significant differences between TOC groups and some of the AWH groups in the amount of force required to dislodge or fracture the crown. The data correlates with a predictable pattern that the TOC and AWH have significant impact on mean load of failure, and it follows the previously established requirements for retention and resistance form (Goodacre *et al.*, 2001). As TOC increases and AWH decreases, there will be an increase in risk of crown failure. This study found that abutments with 4mm of AWH with 7° or 15° TOC are significantly more likely to prevent crowns debonding than other groups. This finding supports the importance of AWH and TOC even with adhesive bonding.

Additionally, like many *in vitro* studies, the results of this study do not necessarily associate with *in vivo* conditions. Many factors can contribute to restoration failure such as load frequency, vector, duration, and distribution as well as aging and degradation of the resin bond in the oral environment. It would be impractical to account for all these in an *in vitro* investigation. Further research is needed to examine the mechanisms of failure of 5Y-ZP zirconia crowns cemented to 5Y-ZP zirconia custom implant abutments.

## CONCLUSION

The results of this *in vitro* study indicate that 5Y-ZP zirconia crown adhesively bonded with resin cement system will dislodge from 5Y-ZP zirconia custom implant abutment due to lack of resistance form. At least 4mm AWH with 7° or 15° TOC are required to resist crown from debonding within the average maximum biting forces.

## ACKNOWLEDGMENTS

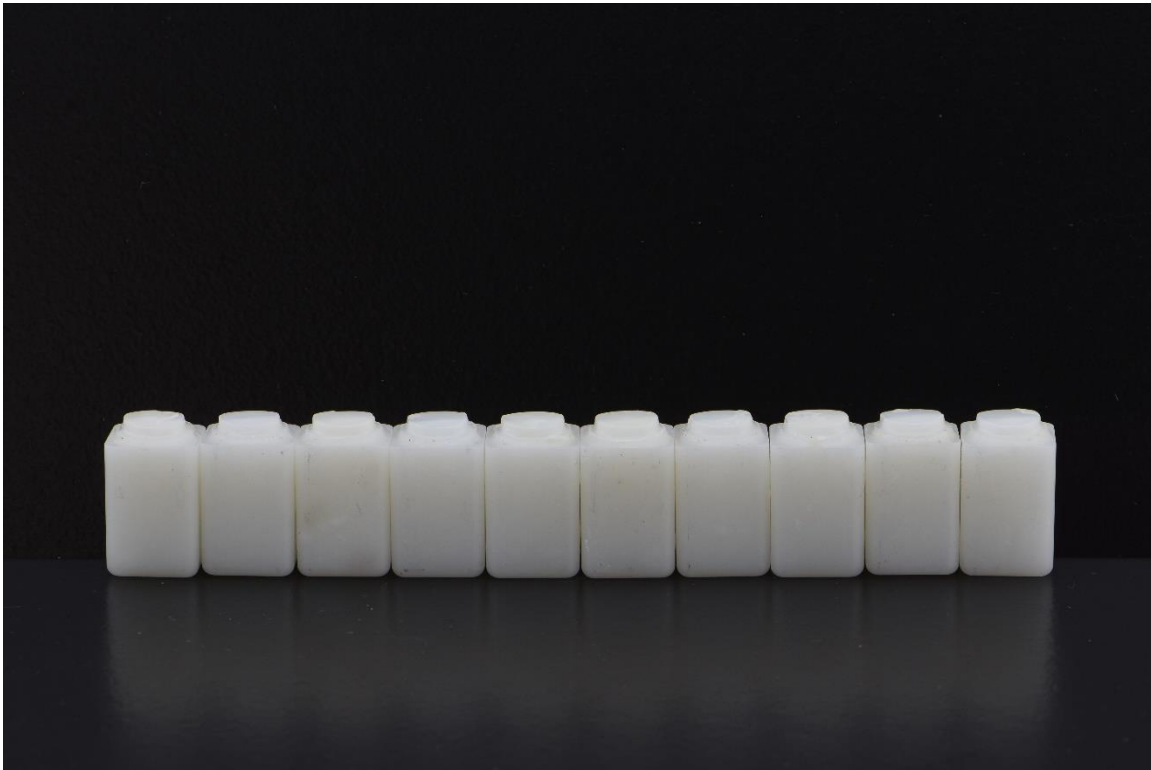
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## DISCLOSURES

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

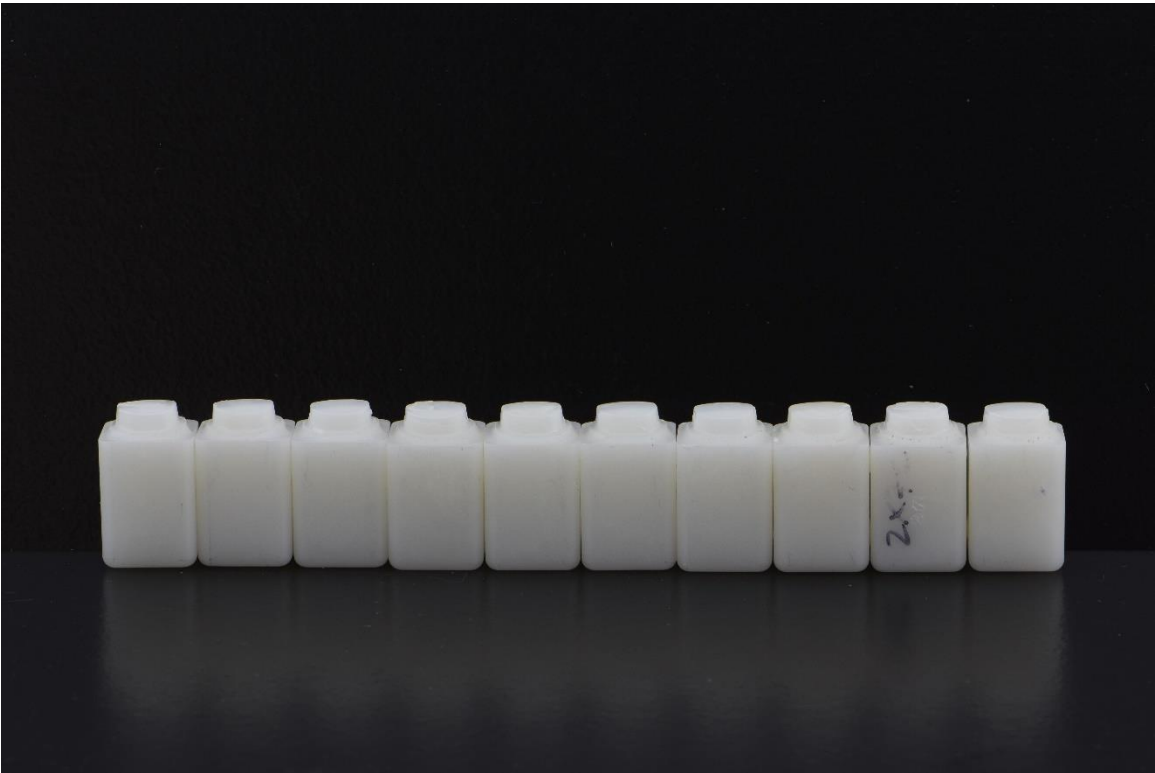
1mm x 7°



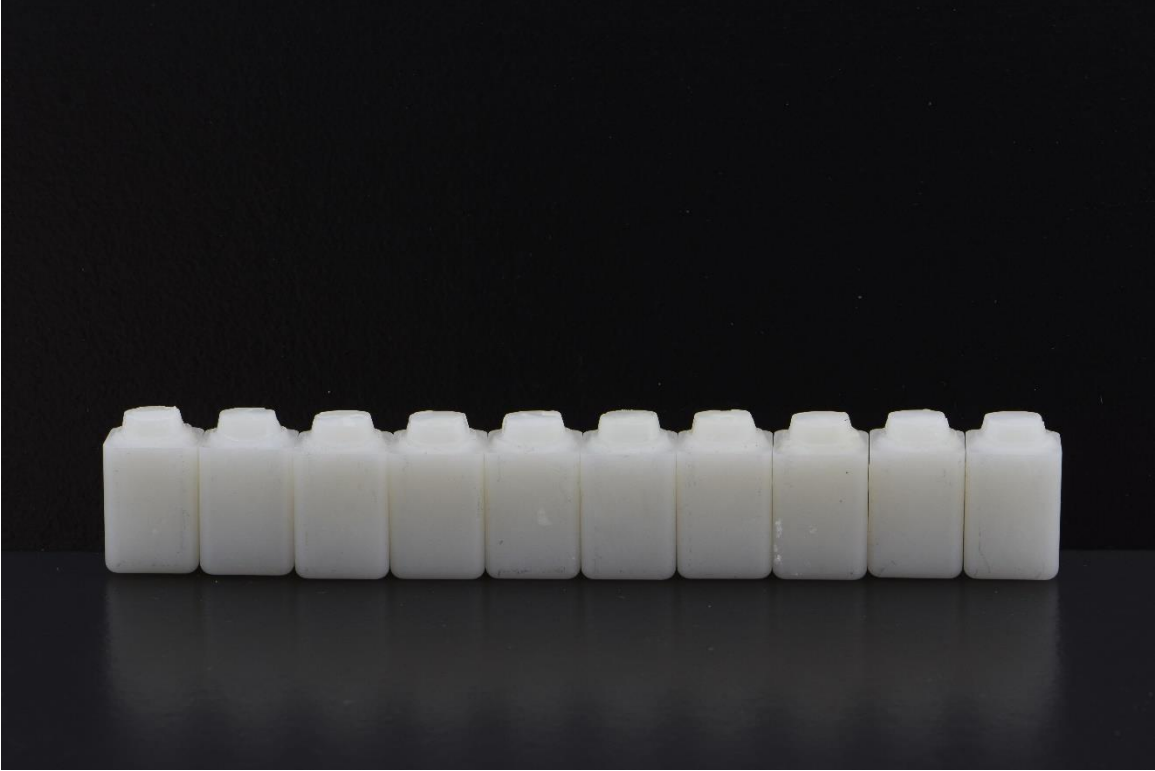
1mm x 15°



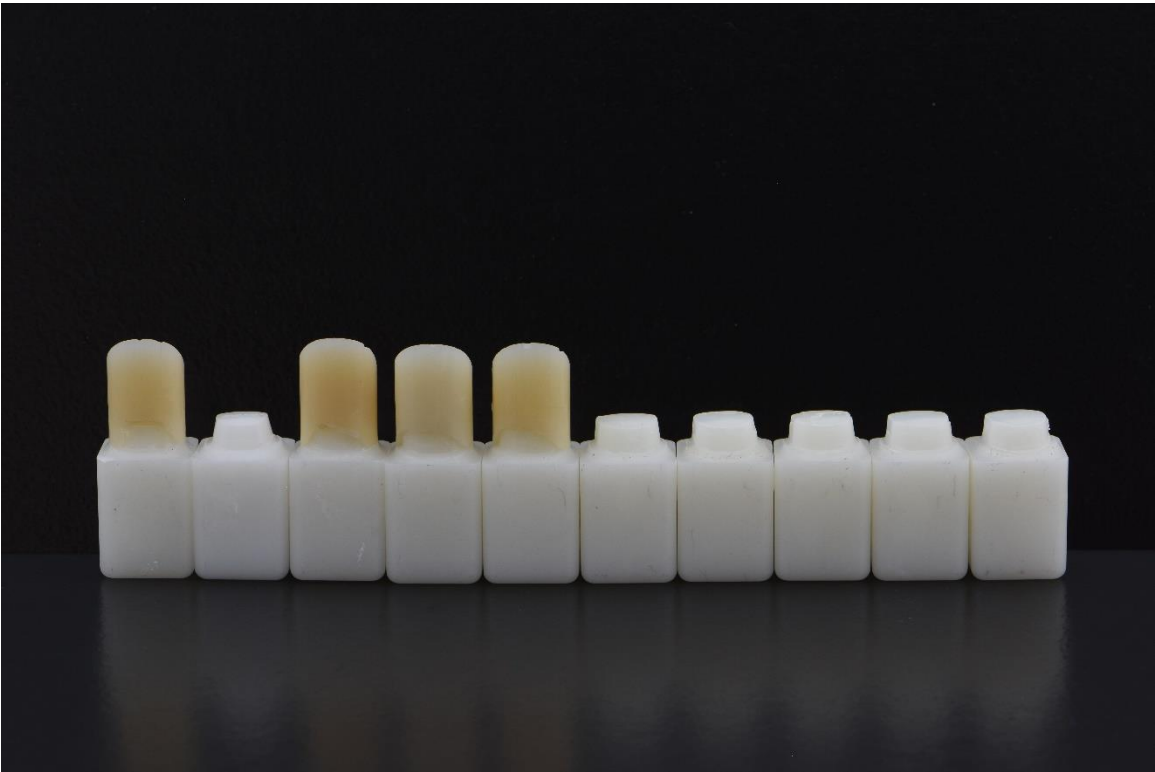
2mm x 7°



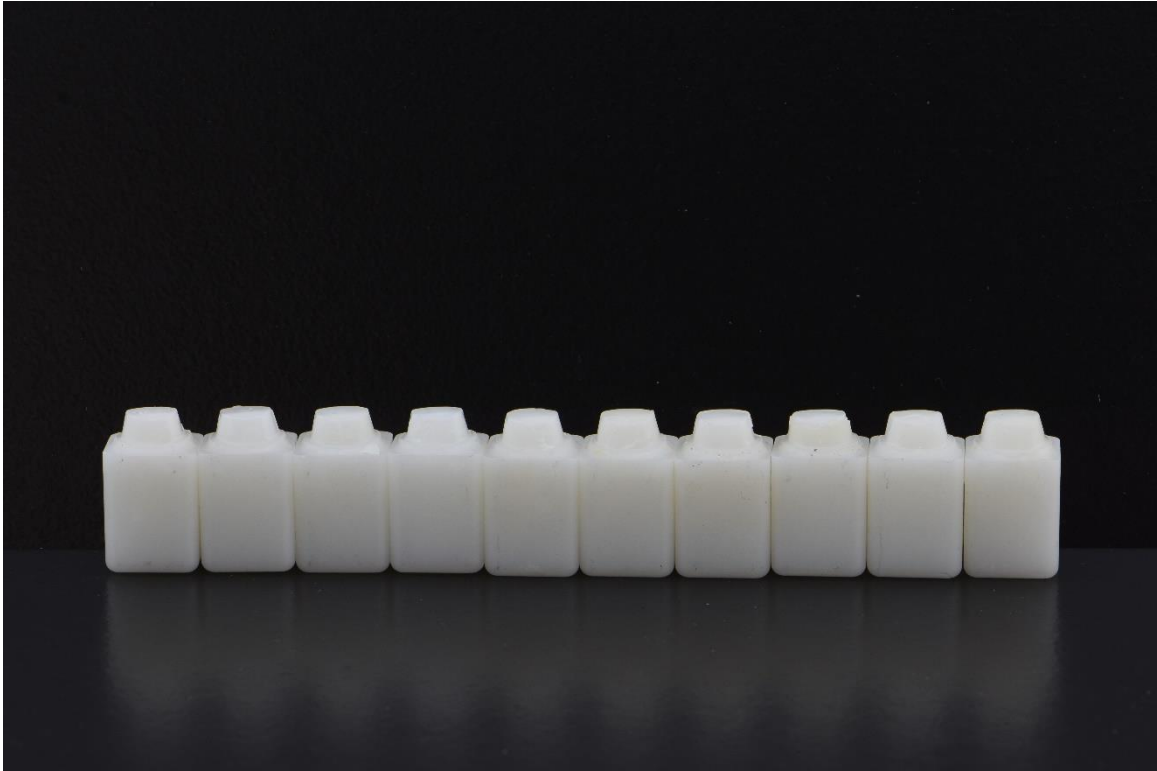
2mm x 15°



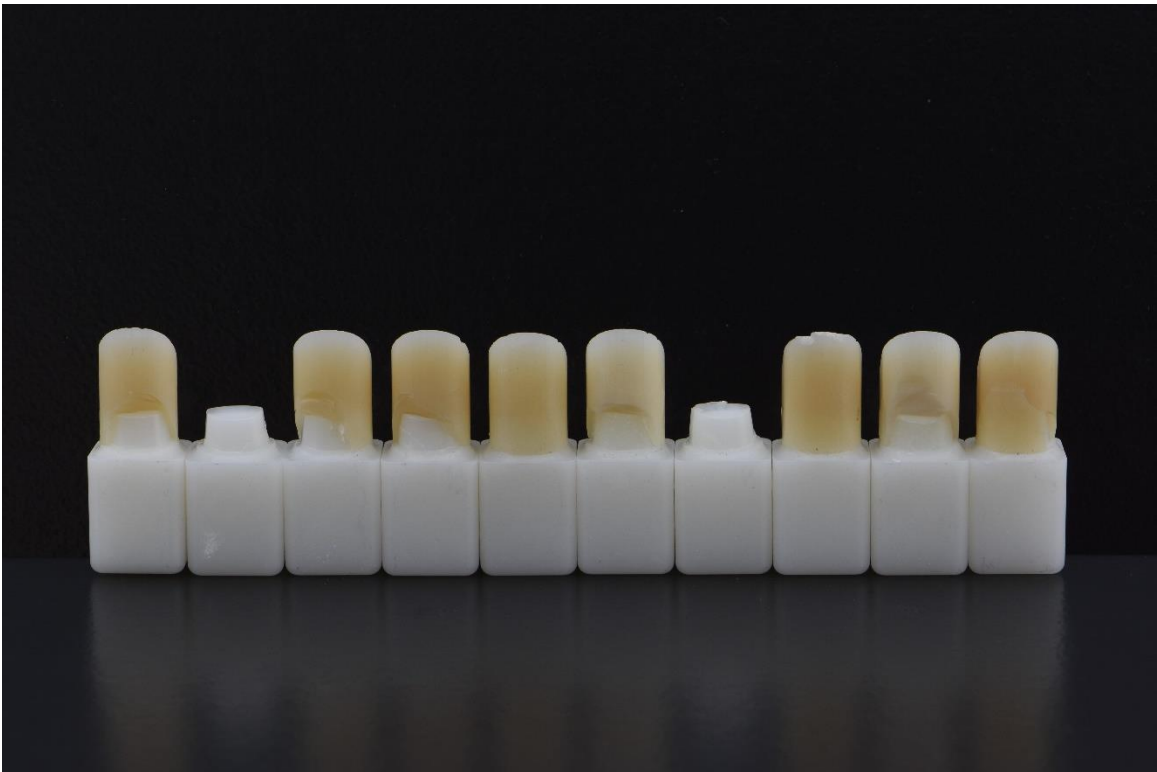
3mm x 7°



3mm x 15°



4mm x 7°



4mm x 15°



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