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Effect of axial wall height and total occlusal convergence on retention of lithium disilicate adhesively bonded to lithium disilicate

Troy M. Decker, DDS

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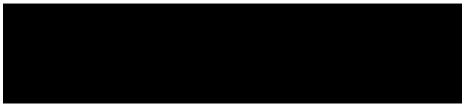

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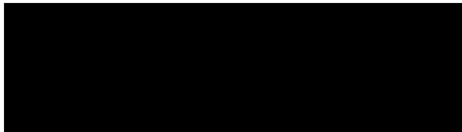

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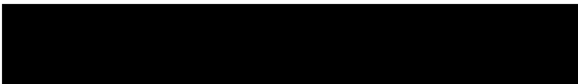

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EFFECT OF AXIAL WALL HEIGHT AND TOTAL OCCLUSAL CONVERGENCE ON RETENTION OF LITHIUM DISILICATE ADHESIVELY BONDED TO LITHIUM DISILICATE

A
Thesis

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ABSTRACT

Statement of Problem: Currently, no published data exists to provide clinical guidance on decisions relative to axial wall height and degree of occlusal convergence regarding crowns that can be bonded, instead of merely luted, to a lithium disilicate implant supported custom abutment.

Purpose: The purpose of this study was to quantify the effect that axial wall height and degrees of total occlusal convergence had on the resistance to dislodgement of lithium disilicate crowns bonded to lithium disilicate custom implant abutments.

Material and Methods: Eight groups of ten lithium disilicate (IPS emax, Ivoclar Vivadent, Inc., Amherst, NY) crown and abutment pairs (n=10) were fabricated. Each group differed in axial wall height and total occlusal convergence of the abutment and corresponding crown. Lithium disilicate crowns were adhesively bonded to lithium disilicate abutments using the Panavia V5 (Kuraray North America, Houston, TX) resin cement system. Following cementation, samples were artificially aged, 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 each sample to failure (fracture or debonding). The mode of failure and load at which failure occurred was recorded.

Results: Mode of failure for 98.73% (78 of 79) samples across all groups was fracture of ceramic as opposed to debonding alone.

Conclusions: Results of this *in vitro* study indicates that bonded crown and abutment specimens will not result in dislodged crowns due to lack of resistance form regardless of axial wall height or TOC. Even a single millimeter of axial wall height at 15 degrees TOC resulted in a crown that remained bonded to its abutment until such a high

level of force was reached that cohesive failure occurred by means of fractured ceramic (at more than double the force from average human bite-force) rather than failure of the resin bond.

CLINICAL IMPLICATIONS

When using a split file technique to fabricate single unit implant supported restorations, an axial wall height of 1 mm with a total occlusal convergence of 15 degrees will resist dislodging forces.

INTRODUCTION

Endosseous dental implants as well as their prosthetic restorations have undergone continuous improvement in recent years (Christensen, 2008), but providers are still faced with certain complexities when considering a restorative material's mechanical properties, esthetics, as well as effects on peri-implant health.[1] Single-unit implant crowns have two options for prosthesis retention: screw-retained (i.e. - implant supported) or cement-retained (i.e. - abutment supported). Each of these restoration types has unique advantages and disadvantages.

Screw-retained or implant-supported crowns permit attachment of coronal components directly to the implant without an intermediary abutment. The contour of these restorations is entirely custom, fabricated either manually via the lost wax technique (full-metal or PFM) or digitally via computer aided design/computer aided manufacture (CAD/CAM) equipment. The screw-retained restoration has two significant advantages. First, there is no excess cement to remove, thus eliminating an important potential source for implant failure due to undetected residual excess cement. Second, this design allows for relatively simple removal of the prosthesis should the need arise.[2-5] This type of

restoration presents with relative disadvantages which include a compromised esthetic result if the implant angulation is such that the screw access would be required to exit through anything other than the occlusal (in the case of a posterior unit) or incisolingual (in the case of an anterior unit) surface of the crown. An additional disadvantage is that the screw-retained implant supported crown can be relatively tedious for practitioners to fit during definitive placement, especially in the posterior dentition.

A cement-retained or abutment supported crown represents another restorative option for a single implant. This restoration is essentially a traditional crown cemented to a prosthetic abutment. It is the abutment which serves as the connection to the implant. These abutments can be either prefabricated (stock) or custom fabricated. The prosthetic crown to be cemented onto the abutment also has a wide variety of material options to include cast gold, porcelain fused to metal, zirconia, or all-ceramic.[6] One distinct advantage to the cement-retained crown is the ability to compensate for off-angled implants by concealing the screw access of the abutment beneath the crown. Additionally, cement-retained crowns are much easier to insert as once the abutment is in place, the adjustment and cementation is nearly identical to that of a traditional tooth-borne crown. A significant disadvantage of the cement-retained implant supported crown is the potential to leave undetected residual cement after definitive cementation to the abutment, which can lead to relatively rapid and unpredictable peri-implant bone loss and eventual implant failure.[4, 5, 7] It is for this reason that Linkevicius, Wadhwani and others have recommended that this risk be reduced by limiting the subgingival depth of the crown-abutment junction though the exclusive use of custom abutments.

Custom abutments can be created in a number of ways, based on their design and production method (analog vs digital) and choice of abutment material. Much like the previously mentioned manufacture methods for the screw-retained restorations, custom abutments can either be fabricated via the lost wax or CAD/CAM techniques. The lost wax technique yields abutments made of any number of castable alloys. CAD/CAM abutments can be milled from titanium, zirconia, or various types of ceramics and ceramic-resin hybrid materials.[6]

Custom gold abutments have been widely accepted and used when the main considerations for the restoration are strength and prosthetic support, but the metallic color may yield compromised esthetic results due to the relative translucency of all ceramic crowns or may result in metal show-through at the gingival margin in patients with thin gingival biotypes.[8] Custom gold abutments are also relatively difficult and labor intensive to fabricate.[9]

The use and continuous advancements of CAD/CAM capabilities in the dental field has made it possible to manufacture custom abutments from milled materials such as zirconia, lithium disilicate, lithium silicate, and hybrid resin/ceramic materials. Custom milled implant abutments can be fabricated in one of two ways: 1) abutments may be digitally designed and milled, then a corresponding crown either digitally or traditionally designed to fit the abutment; 2) by digitally designing a monolithic single unit screw retained implant abutment/crown, then in the design software, the monolithic restoration is "split" into a custom abutment and corresponding crown, thereby resulting in a milled custom abutment and milled single unit crown to be cemented to that custom abutment. This is commonly referred to as a "split file" restoration/technique. Using this technique,

an operator can choose any commercially available millable material(s) for use as the crown and abutment.

Custom zirconia abutments are widely used, especially when esthetics are of primary concern. Zirconia abutments display acceptable fracture resistance for use as abutments, as well as resistance to dislodgement with adhesive bonding.[9, 10] This adhesive bonding is possible with all ceramic crowns and zirconia abutments due to 10-methacryloyloxy-decyl-dihydrogen-phosphate (10-MDP) primers which create ionic and hydrogen bonding between the resin cement, 10-MDP molecules, and zirconia.[11] A drawback to using custom zirconia abutments is the inability for same-appointment delivery due to the 2 to 8-hour sintering process, as well as the requirement for a separate sintering oven.[6] It should be noted that one company recently developed a sintering oven for a 15-minute chairside glaze and sinter process (Dentsply Sirona, York, PA); relatively little data exists, however, relative to the long term properties of a "15-minute sintered" zirconia prostheses.

Lithium disilicate glass ceramic, a widely available ceramic material, also may be considered as an abutment option for cement-retained implant supported crowns. Lithium disilicate was initially introduced by Ivoclar in 1998 as Empress II, and later reintroduced in 2007 as IPS e.max. Advantages of lithium disilicate abutments include ease of fabrication, professional familiarity, strong covalent bonding is possible between the resin cement, silane, and silicate-based lithium disilicate, and the potential for single-appointment implant restoration fabrication and placement due to the relatively short crystallization firing cycle of about 25 minutes (which can be accomplished in a traditional ceramic firing oven).[12] Additionally, studies have demonstrated that lithium disilicate

performed just as well as zirconia and titanium abutments to fracture resistance during *in-vitro* testing, and CAD/CAM manufactured crowns and corresponding abutments designed by the "split file" workflow have a clinically acceptable margin fit and adaptation with a marginal gap of 69 micrometers on average.[9,13]

Traditional thought in fixed prosthodontics maintains that cement alone is not enough to prevent dislodgement of a crown from the underlying tooth or abutment. The primary contributing factor to prevention of crown dislodgement is resistance form built into the abutment or underlying tooth.[14, 15] It has been demonstrated that for a crown to have proper resistance form, it must have adequate axial wall height and total occlusal convergence (TOC) to resist rotation off an abutment.[16] As axial wall height decreases, TOC must decrease *i.e.* become more, and as the occlusal table dimension increases, axial wall height must increase as well.[17, 18] In 2001, Goodacre *et al.* summarized the findings of the previous 121 years regarding tooth preparations for cement-retained crowns. The findings showed to achieve adequate resistance form, a TOC of 10-20 degrees is required with a minimum of 4 mm of axial wall height in molars and 3 mm of axial wall height in premolars.[19] If these parameters outlined by Goodacre are not satisfied, auxiliary features such as proximal grooves may be utilized to relatively improve resistance form of the tooth/abutment down to 3 mm of axial wall height.[20]

These recommendations for resistance form were developed when luting cement was the primary option for definitive crown placement. A luting cement is defined as a material that simply fills a gap between two materials, *i.e.*, tooth and crown, thereby mechanically locking the crown to the tooth. These resistance form properties outlined by Goodacre *et al.* may not be necessary when an adhesive bond between the crown and

abutment is present. This is due to the nature of adhesive bonding, which creates an "atomic attraction between two contacting surfaces promoted by the interfacial force of attraction between the molecules or atoms of two different species", which can be chemical in the form of covalent, hydrogen, or polar bonds.[12]

Recent results indicate the advancement of resin cements may permit adhesive bonding of ceramic onlays to natural tooth abutments with less than recommended axial wall heights and may produce favorable long term in-vivo survival rates at 5 and 10 years of 92-95% and 91% respectively.[21,22]

When applying the principles of resistance form to cement-retained implant crowns, complications can arise since the implant supported prostheses must have adequate occluso-gingival space. Misch described the sum of the spaces necessary for an implant restoration as crown height space (CHS). He concluded that a minimum of 8 mm of vertical height is required between the implant platform and the planned occlusal surface based on the need for 2 mm of occlusal thickness of the crown for strength and fracture resistance, 4 mm of abutment height for resistance form, and 2 mm between the implant platform and crown margin for biologic width dimension.[23, 24]

In the CAD/CAM design process for implant restorations, it sometimes happens that upon splitting the planned full contour restoration into abutment and crown, the resultant abutment may have an axial wall height shorter than the traditionally held minimum of 3 mm (premolar) or 4 mm (molar), due to limited CHS. One temptation in the design process may be to move the crown/abutment margin farther apically to gain axial wall height. As previously discussed, however, this decision is undesirable because it places the crown-abutment junction further subgingivally, increasing the risk of undetected

residual cement.[25] Therefore, the designer is left to choose either an abutment with less than the "ideal" traditional axial wall height/resistance form requirement or, a return to the monolithic screw-retained design.

One is left to wonder, with the ability to bond the crown to the abutment, what impact varying axial wall height might have on the resistance form of cement-retained implant restorations, and additionally what impact variations in total occlusal convergence has on that measurement.

Numerous investigators have tested resin cement bond strength for lithium disilicate bonded to natural tooth and zirconia, but no researchers have measured the effect of different axial wall heights and different degrees of total occlusal convergence on resistance form of adhesively bonded lithium disilicate crowns to lithium disilicate abutments.

The purpose of this study was to quantify the effect that axial wall height and degrees of total occlusal convergence had on the resistance to dislodgement of lithium disilicate crowns bonded to lithium disilicate custom implant abutments.

HYPOTHESIS

Null hypothesis: There is no statistically significant difference in the amount of force required to dislodge lithium disilicate crowns bonded to lithium disilicate abutments when the axial wall height of the abutment and the total occlusal convergence of those axial walls varies.

Alternative hypothesis: The amount of force required to dislodge lithium disilicate crowns bonded to lithium disilicate abutments differs significantly when the axial wall height of the abutment and the total occlusal convergence of those axial walls varies.

SPECIFIC AIMS

A lithium disilicate single unit crown adhesively bonded to a lithium disilicate implant abutment is a relatively new technique made possible by the continuous advancements and now widespread use of computer aided design/computer aided manufacture (CAD/CAM) capabilities in the dental field. This restoration is fabricated by digitally designing a single-unit screw retained implant abutment/crown. Then subsequently, in the crown design software, this single restoration file is "split" into a custom abutment and corresponding crown, thereby resulting in a milled custom abutment and milled single unit crown. This is commonly referred to as a "split file" restoration/technique.

The main advantage of this split file restoration is that it allows for the rapid manufacture of both an abutment and a crown in a single process. Because of this streamlined one-step process, the requirements for manpower and fabrication time are significantly reduced, which in turn results in more rapid completion of patient treatment, thus improving military readiness. To fully capitalize on this new capability, though, we must ensure that the resultant product is as reliable as those produced by traditional methods.

The purpose of this study is to quantify the effect that the axial wall height and degrees of total occlusal convergence have on the resistance to dislodgement of lithium disilicate crowns bonded to lithium disilicate custom implant abutments.

MATERIALS & METHODS

Abutments were designed using Sirona InLab 16.1 design software. The end product of this design process were STL-design files that were sent to a milling center

(Imagine Milling, Chantilly, VA) for production. The study consisted of eight test groups. These eight groups of ten samples each resulted from the combination of four axial wall heights [Figure 1] and two different degrees of total occlusal convergence [Figure 2]. Abutments were designed with a shoulder margin with 1.5 mm axial depth. As shown in Figure 1, the axial wall heights were 4 mm, 3 mm, 2 mm and 1 mm. The designed total occlusal convergence variations were 7 degrees and 15 degrees. Abutments were fabricated from lithium disilicate (IPS emax CAD, Ivoclar Vivadent, Inc., Amherst, NY). The groups consisted of 10 samples each (N=10). Each custom abutment sample was designed with a 20 mm extension base apical to the finish line of the abutment. This extension was utilized for fixation in the testing device.

Each abutment had a corresponding lithium disilicate (IPS emax, Ivoclar Vivadent, Inc., Amherst, NY) 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 a uniform axial wall thickness of 1.5 mm.

Each crown and abutment was prepared for adhesive bonding by etching the intaglio surface (crown) and cameo surface (abutment) with 5% hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent, Inc., Amherst, NY) for 20 seconds then rinsed with water, dried with compressed, oil free air at 30 PSI for 10 seconds. Next, ceramic primer (Kuraray, Houston, TX) was applied to each aforementioned surface per manufacturer instructions and allowed to react for 60 seconds, then dispersed with a stream of compressed, filtered, oil free air at 30 PSI for 2 seconds. Subsequently, Panavia V5 (Kuraray, Houston, TX) 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 5 minutes (Mannix Timer) [Figures 4-6].

Following cementation, samples were stored at 37ºC in 100% humidity for 24 hours, then thermocycled for 500 cycles according to ISO/TS 11405 standard for intermediate aging protocol prior to failure testing.[26] The emax crown/abutment prosthesis was inserted into a custom-milled CoCr abutment holder which was mounted into an Instron Universal Testing Machine (Instron, Norwood, MA). Forces directed at 45º to the long axis of the prosthesis were applied to each sample to failure (fracture or debonding) or a maximum load of 10,000N advanced at a rate of one millimeter per minute is attained [Figure 7]. The load at which failure occurred or the maximum load attained, in the event of no failure, 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 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 height (4 levels) as well as the interaction term, when testing with a two way ANOVA at the alpha level of 0.05 (NCSS PASS 2012).

RESULTS

The mode of failure for 98.73% (78 of 79) samples across all groups was fracture of ceramic as opposed to debonding alone, with a total of 69 of 79 fractured abutments, nine of 79 fractured crowns with abutments intact, and one dislodged crown involving no fracture of the ceramic abutment or crown [Table 1]. One sample in the 1 mm x 15 degrees group was not included due to malfunction of the testing equipment during testing, and one

crown in the 4 mm x 7 degrees group dislodged from the abutment with only 12.75 N likely due to an error during sample preparation and cementation.

Even though the purpose of this study was to examine dislodgement (occurred one time), load-break data was collected and so it was calculated and tabulated. SPSS computer software was used to calculate the means and the standard deviations for each test group. Afterwards, two-way ANOVA and one-way ANOVA were used to determine whether significant differences existed among the study groups (i.e. axial wall height and total occlusal convergence), followed by Tukey pairwise multiple comparisons at 95% confidence interval, which were performed to determine which total axial wall height group at a given occlusal convergence group significantly differed from the other.

Mean and standard deviations of the load at failure are summarized [Table 2]. The 2 mm x 7-degrees group had the highest mean fracture load at 1809.20 N, followed by 4 mm x 15-degrees at 1562.22 N, and the lowest mean fracture load was with the 1 mm x 15-degrees group at 1159.15 N. Figure 8 shows the distribution of data.

Two-way ANOVA between axial wall height and total occlusal convergence showed a statistically significant difference in mean values for fracture load based on axial wall height ($p=0.003$), but did not show a significant difference between mean values for fracture load based on total occlusal convergence ($p>0.05$), and the interaction term is statistically significant ($p=0.005$) [Table 3].

One-way ANOVA comparing mean fracture loads for each different axial wall height at 7-degrees of total occlusal convergence showed a statistically significant difference ($p=0.004$) between those four groups, and each different axial wall height at 15-

degrees of total occlusal convergence also showed a significant difference of mean fracture loads between those four groups (p=0.015) [Table 4].

One-way ANOVA comparing mean fracture loads between 7-degrees and 15-degrees of total occlusal convergence at a given axial wall height only showed a significant difference between those two variables when the axial wall height was 2 mm (p=0.033); when axial wall heights were 1 mm, 3 mm, and 4 mm, no statistically significant difference (p>0.05) was found between fracture loads at 7-degrees and 15-degrees of total occlusal convergence [Table 5].

When comparing mean fracture load between samples where axial wall heights differed but when total occlusal convergence was 7 degrees, post hoc analysis showed a statistically significant difference between mean fracture loads of 2 mm and 4 mm axial wall heights, but no significant differences otherwise. Likewise, when total occlusal convergence was 15 degrees, 1 mm wall height showed a statistically significant difference in mean fracture load as compared to 2 mm and 4 mm axial wall mean fracture loads, but no significant differences otherwise.

DISCUSSION

The purpose of this study was to quantify the effect that the axial wall height and degrees of total occlusal convergence have on the resistance to dislodgement of lithium disilicate crowns bonded to lithium disilicate custom implant abutments. In only one instance out of 79 did dislodgement even occur. This data clearly shows that none of the variables in the study led to any measurable dislodgement. No clinically significant difference existed between any group, as all but one sample dislodged due to ceramic fracture rather than debonding. The null hypothesis was that no significant difference

existed in the amount of force required to dislodge lithium disilicate crowns bonded to lithium disilicate abutments when the axial wall height of the abutment and when the total occlusal convergence of those different axial wall heights varied. This hypothesis was accepted.

The most important factor to consider in the results of this study is the mode of failure and the mean load required for failure. All but one sample dislodged due to fracture of the ceramic [Figures 9-17]. There was only one sample where the crown dislodged without any ceramic facture, and this dislodged at less than 13 N, which could likely be attributed to an error during cementation of the crown to the abutment.

The design of this study was to attempt to generate the most unfavorable condition *in vitro* in which a ceramic crown cemented to a ceramic implant supported abutment could receive a load *in vivo*; that is-45 degrees off-axis with the lever arm (approximately 14 mm from the point of rotation) approaching the upper limit of what would be encountered clinically, and certainly not the norm. When an abutment height tends to be shorter, this is normally due to limited restorative space, which would assume that the crown would be correspondingly short as well; it would be difficult to imagine a situation when restorative space only allowed a 1 mm tall abutment but required a 14 mm tall crown, which further illustrates that this study produced conditions likely more extreme that would likely be encountered *in vivo*.

Results of this *in vitro* investigation indicated that there were statistically significant differences between some sample groups in the amount of force required to fracture various bonded crown/abutment combinations, but the statistical significance of the results is clinically irrelevant due to the extremely high loads required to cause ensuing fracture of

each sample. The data does show a statistically significant difference between the test groups, but these differences do not correlate with a predictable pattern or with previously established requirements for retention and resistance form of the abutment. It would be expected that the one- and two-mm tall abutments would require a lesser load to dislodge the crown than the three- and four-mm tall abutments, regardless of the total occlusal convergence. It is important to note that the mean *in vitro* load required to dislodge and/or fracture the ceramic was well above the load able to be generated *in vivo.*

As is the case with many *in vitro* studies, the results of this investigation do not necessarily corelate to an *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, and it would be impractical to account for all of them in an *in vitro* investigation. Future research is need to examine the mechanisms of failure of lithium disilicate crowns cemented to lithium disilicate implant supported abutments. It is known that the strength of the resin bond does degrade with time in the oral environment, but no published research has been conducted to date on this topic when the substrate is lithium disilicate.

CONCLUSION

Results of this *in vitro* study indicates that bonded crown and abutment specimens will not result in dislodged crowns due to lack of resistance form regardless of axial wall height or TOC. Even a single millimeter of axial wall height at 15 degrees TOC resulted in a crown that remained bonded to its abutment until such a high level of force was reached that cohesive failure occurred by means of fractured ceramic (at more than double the force from average human bite-force) rather than failure of the resin bond.

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DISCLOSURE

The views expressed in this study are those of the authors and do not reflect the official policy of the United States Air Force, the Department of Defense, or the United States Government. The authors do not have any financial interest in the companies whose materials are discussed in this article.

APPENDIX 1:

Figure 1: Schematic showing varied axial wall heights (return to thesis)

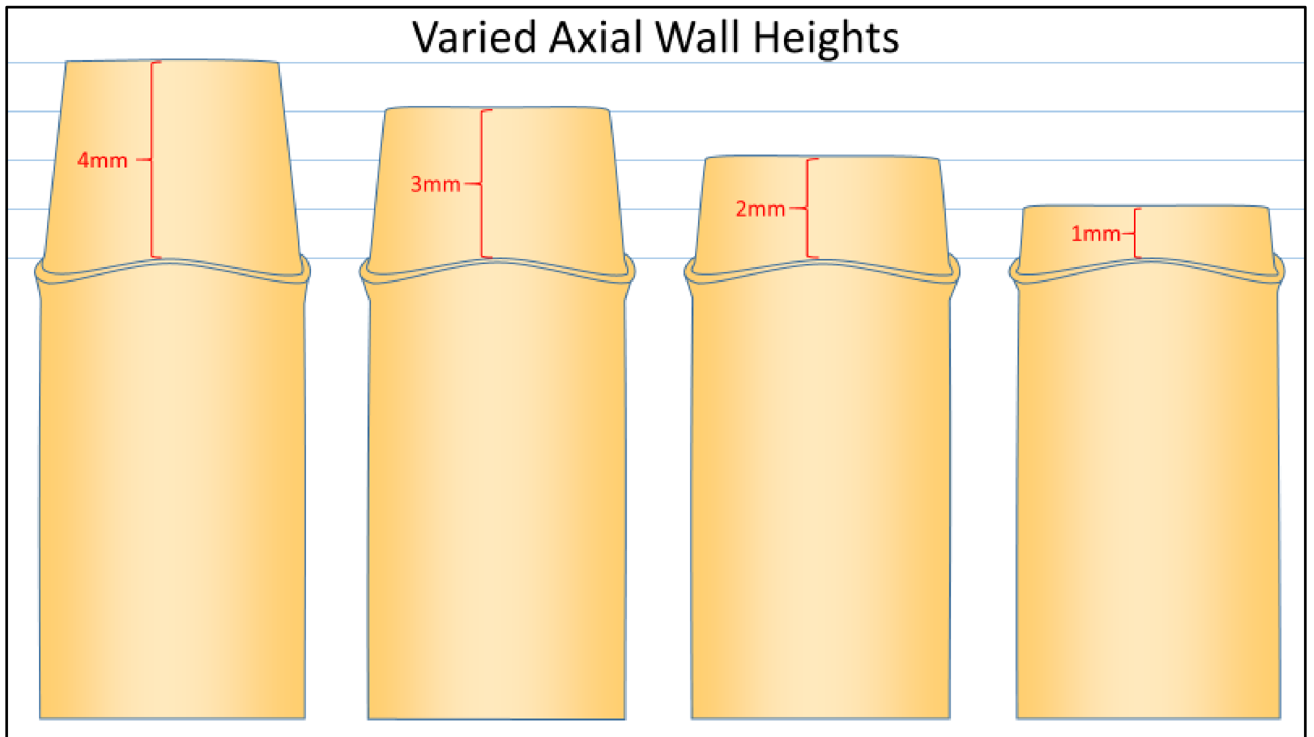

Figure 2: Schematic showing varied total occlusal convergence (return to thesis)

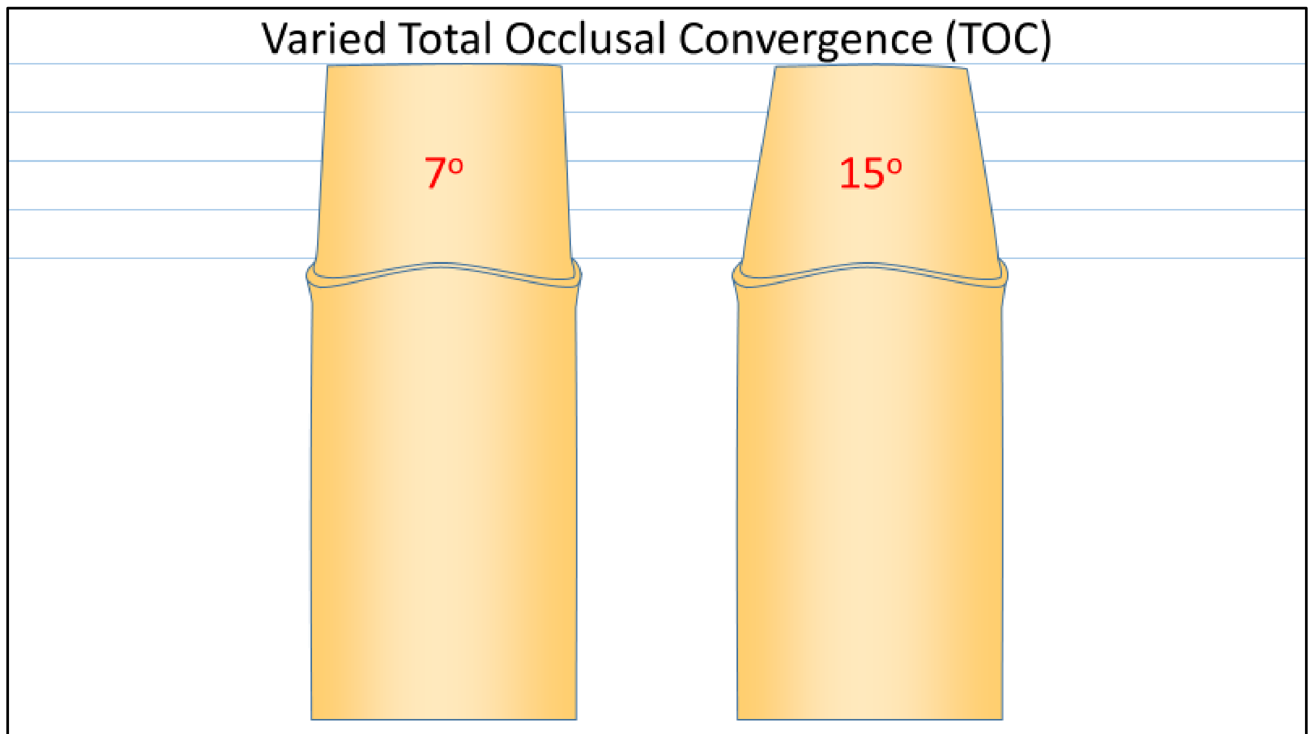

Figure 3: Schematic showing crown design (return to thesis)

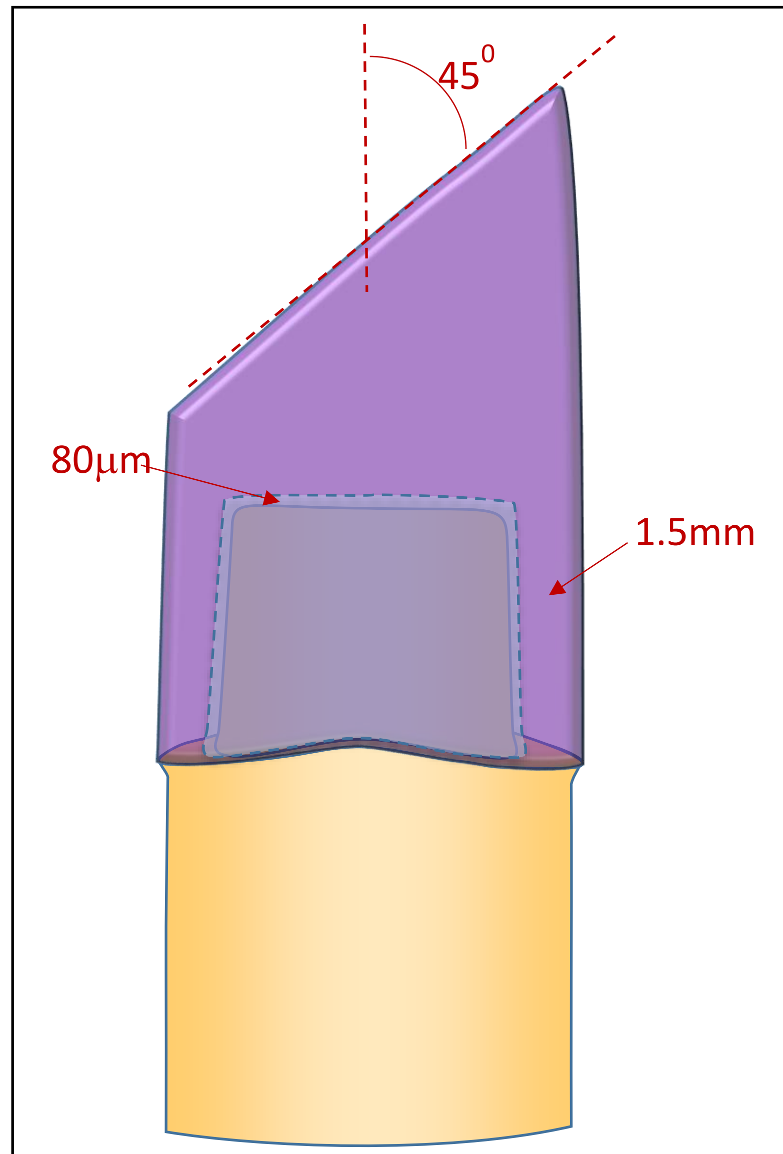

Figure 4: Crown seating index base (return to thesis)

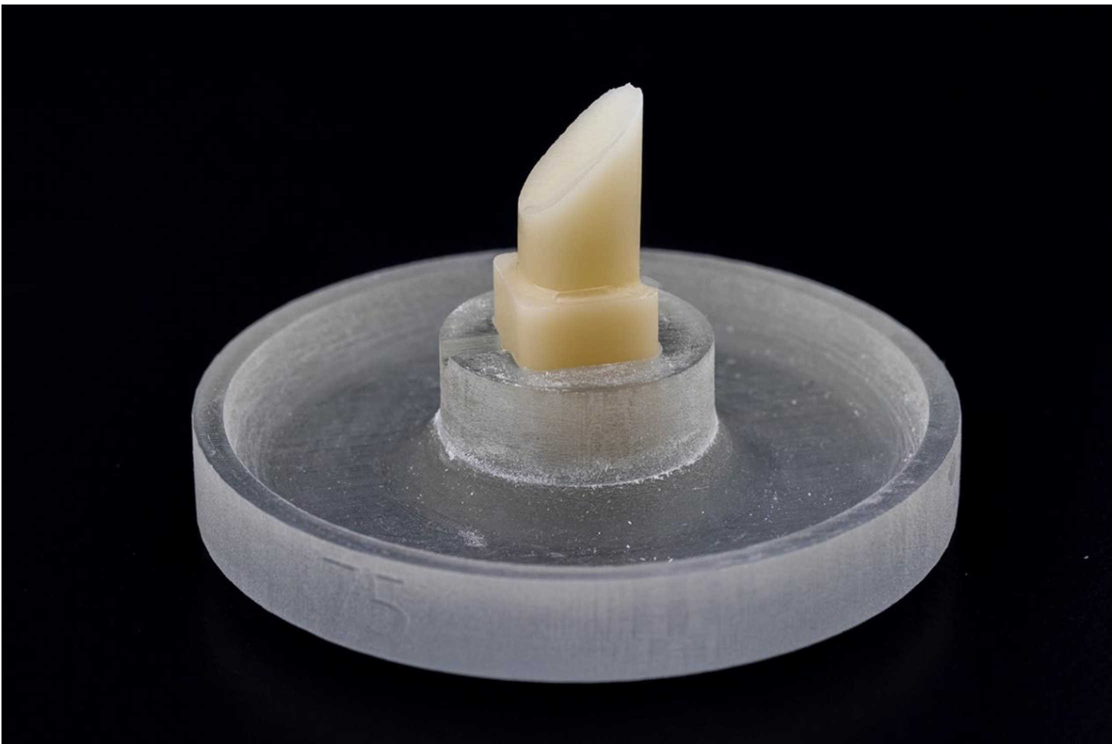

Figure 5: Crown seating index top (return to thesis)

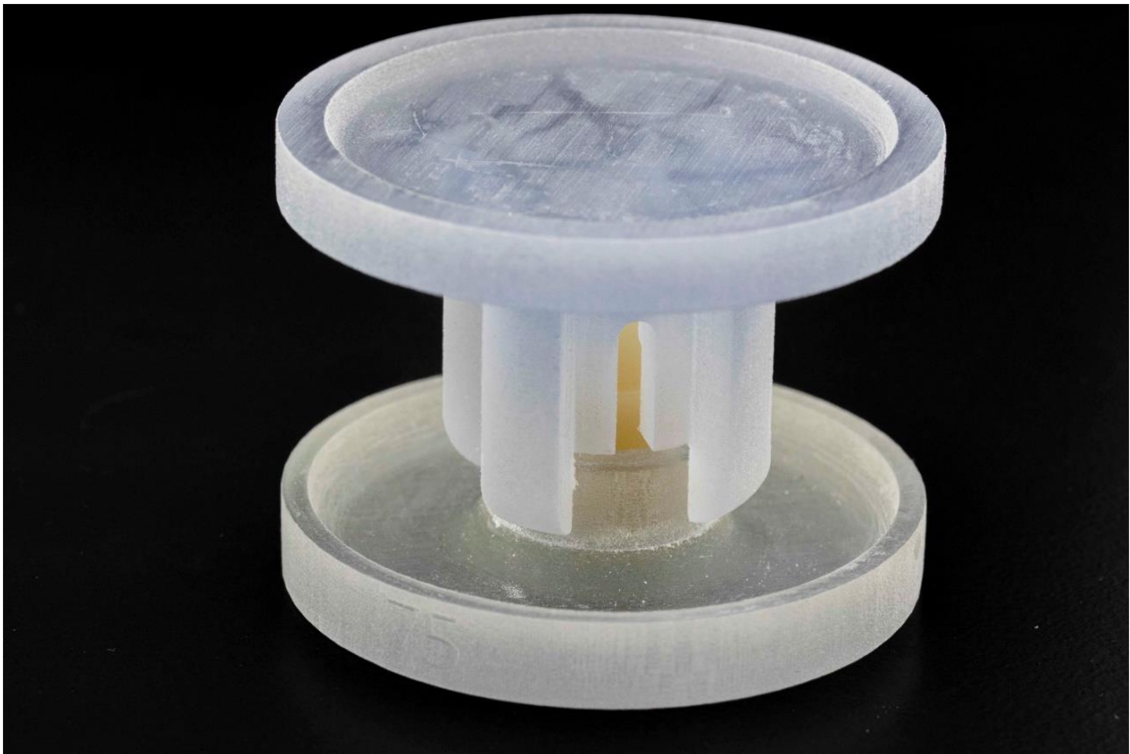

Figure 6: Crown seating index with 10-pound weight (return to thesis)

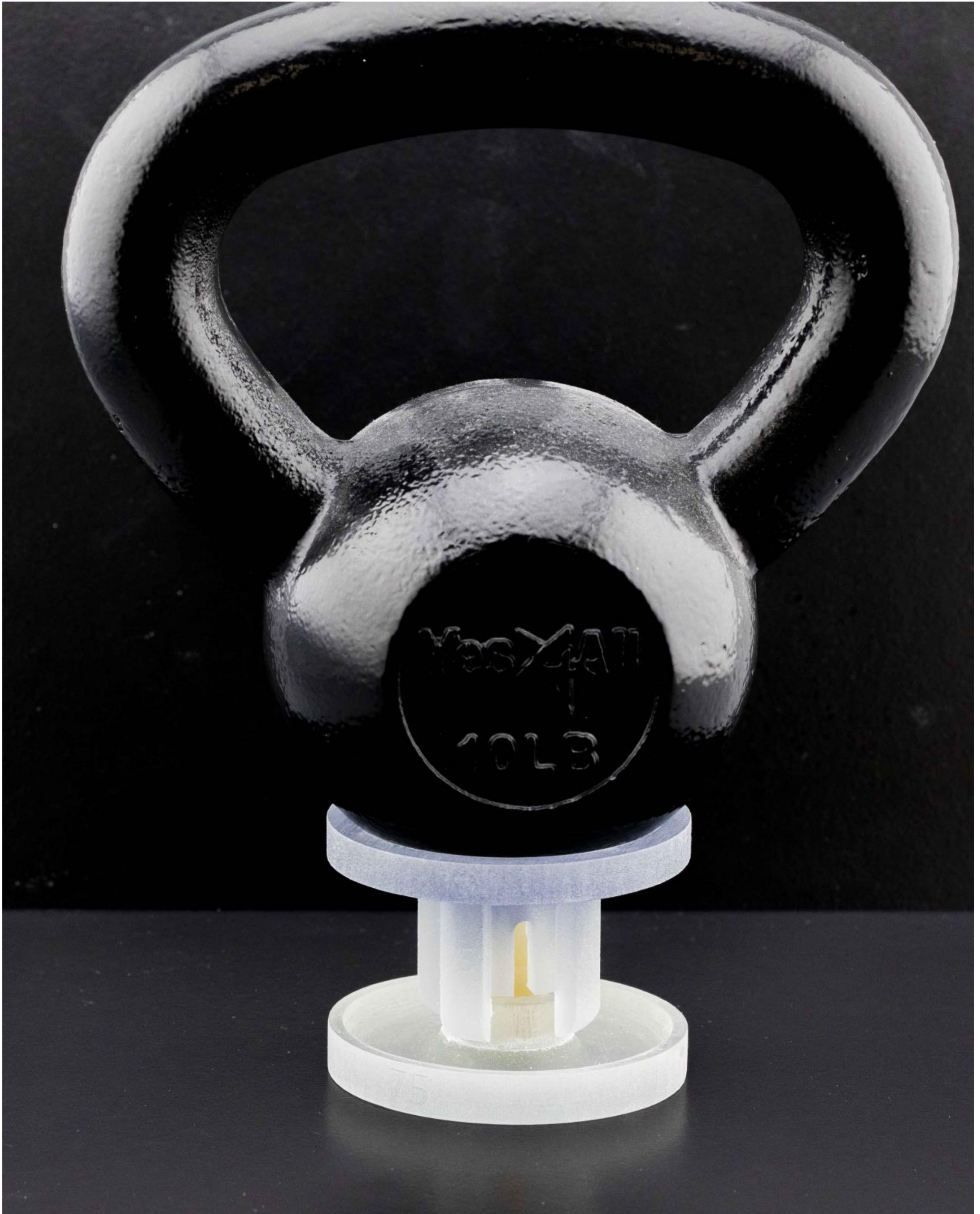

Figure 7: Instron testing assembly (return to thesis)

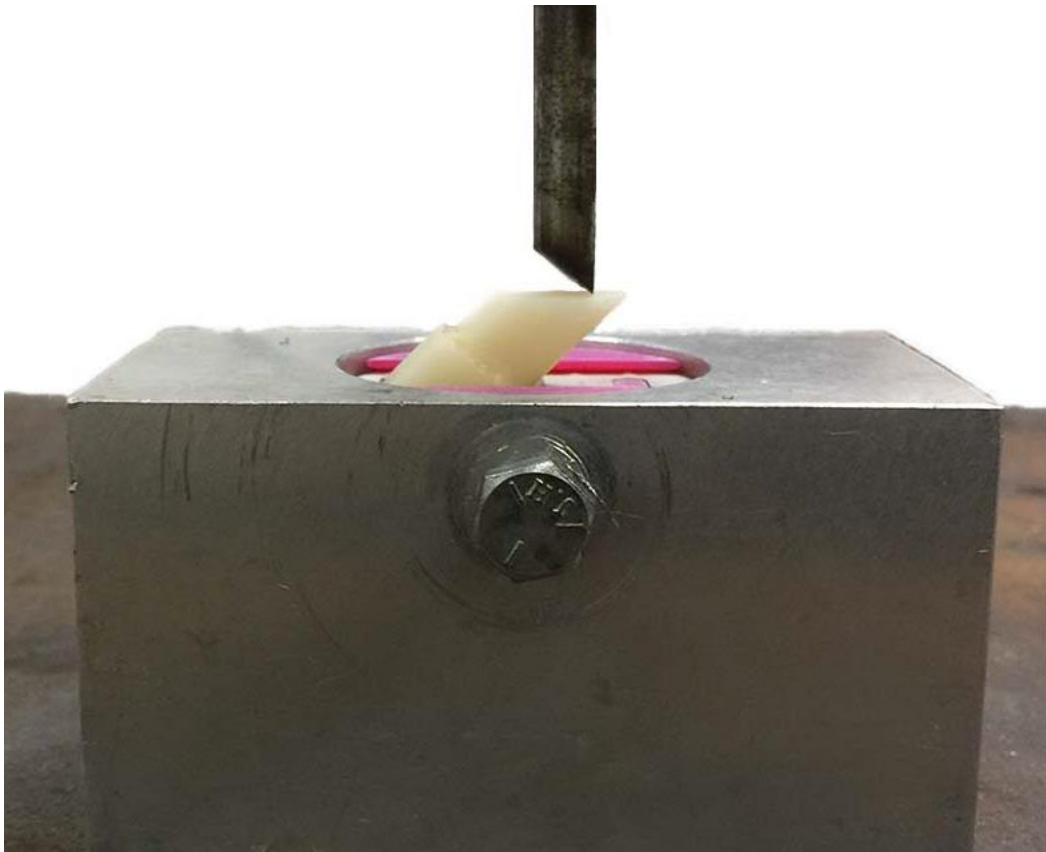

Table 1: Mode of failure for each sample group (return to thesis)

	Total samples	Fractured ceramic	Fractured abutment	Fractured crown only	Dislodged crown/no fracture
1 mm x 7 degrees	10	10	8	2	0
1 mm x 15 degrees	9	9	9	0	0
2 mm x 7 degrees	10	10	10	0	0
2 mm x 15 degrees	10	10	9	1	0
3 mm x 7 degrees	10	10	10	0	0
3 mm x 15 degrees	10	10	10	0	0
4 mm x 7 degrees	10	9	5	4	1
4 mm x 15 degrees	10	10	8	2	0

Figure 8: Boxplots of load at failure for each sample group (return to thesis)

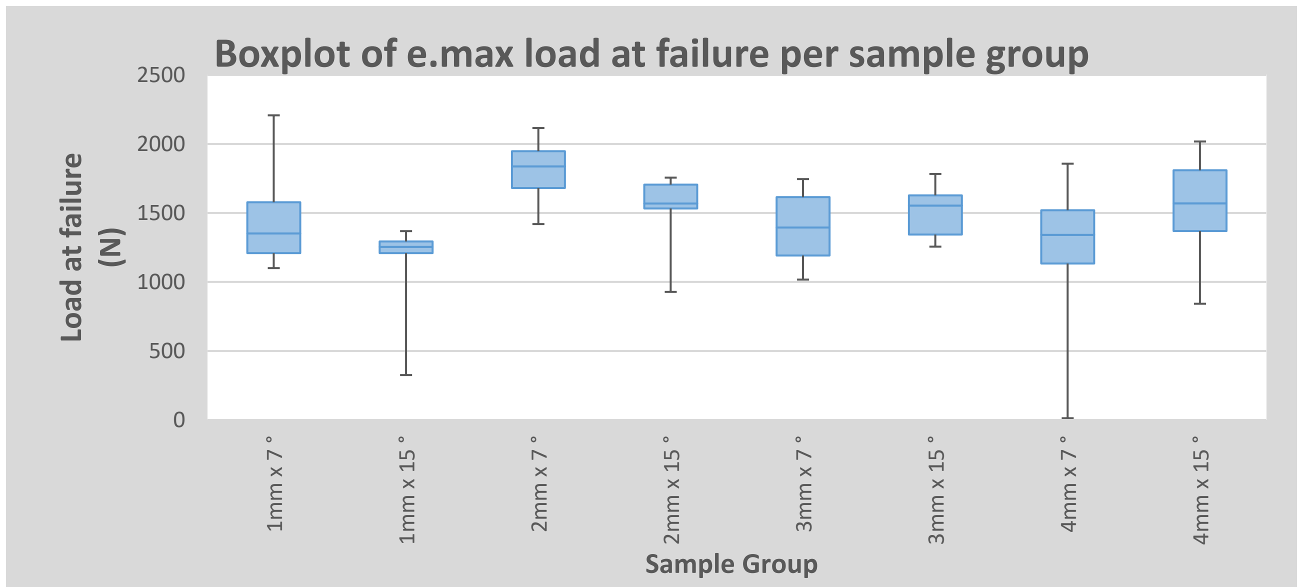

Table 2: Means and standard deviations of load at failure for each group (return to thesis)

Sample Group	Mean Fracture Load (N)	Standard Deviation (N)
1 mm x 7 °	1443.99	327.67
1 mm x 15 °	1159.15	318.00
2 mm x 7 °	1809.20	204.35
2 mm x 15 °	1502.93	283.76
3 mm x 7 °	1404.75	256.33
3 mm x 15 °	1510.23	176.60
4 mm x 7 °	1212.04	522.90
4 mm x 15 °	1562.22	345.92

Table 3: Two-way ANOVA for axial wall height and total occlusal convergence (return)

Axial wall height	Type III Sum of Squares	df	Mean Square	F	Sig.
Axial wall height	1561020.423	3	520340.141	5.014	0.003
Total Occlusal Convergence	11082.676	1	11082.676	0.107	0.745
Axial wall height*Total occlusal convergence	1423337.839	3	474445.946	4.572	0.005

Table 4: One-way ANOVA for axial wall height (return to thesis)

Axial wall height	Type III Sum of Squares	df	Mean Square	F	Sig.
1 mm	417240.091	1	417240.091	3.984	0.06
2 mm	350237.171	1	350237.171	5.362	0.033
3 mm	55635.882	1	55635.882	1.148	0.298
4 mm	613130.06	1	613130.06	3.12	0.094

Table 5: One-way ANOVA for total occlusal convergence (return to thesis)

Total Occlusal Convergence	Type III Sum of Squares	df	Mean Square	F	Sig.
7	1866158.08	3	622052.693	5.129	0.004
15	1012833.981	3	337611.327	3.983	0.015

APPENDIX 2 Photos of sample group abutments after testing and raw load data

Figure 9: 1mm x 7° abutments after testing

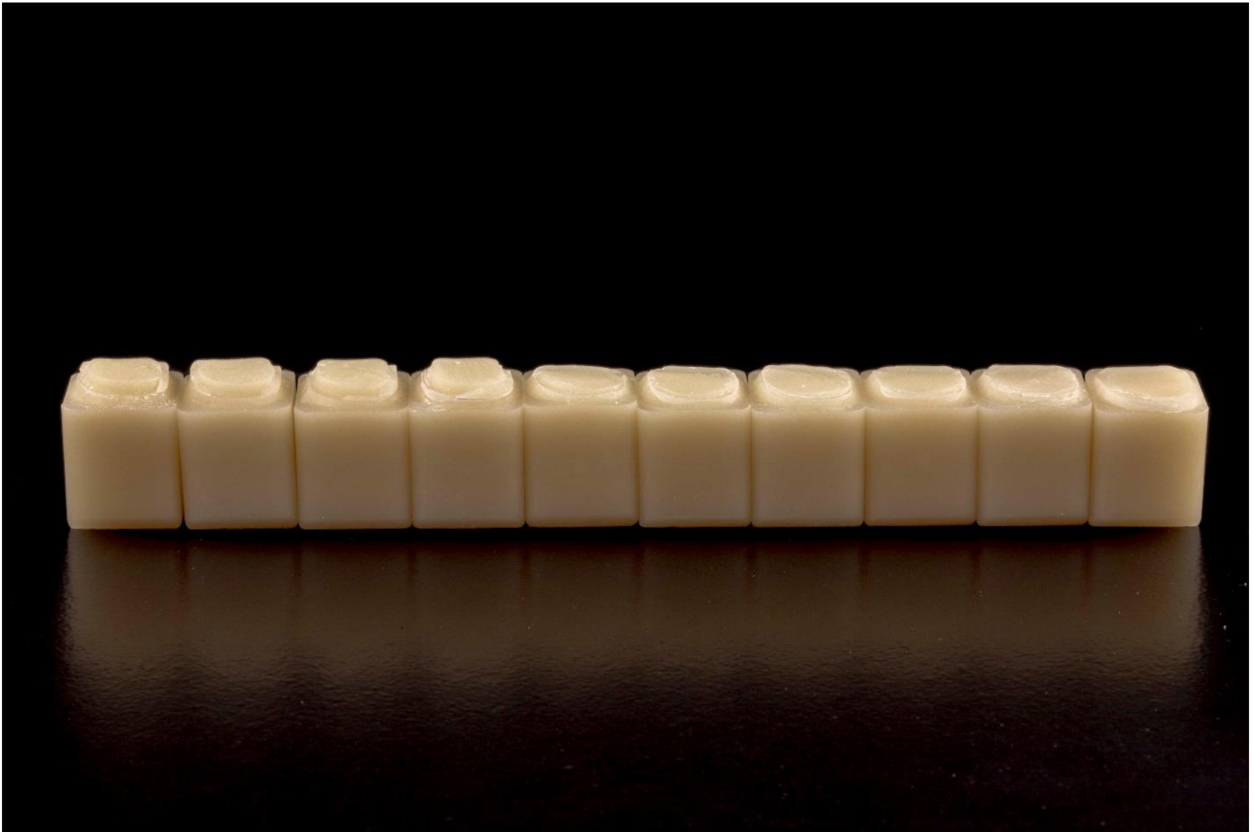

Figure 10: 1 mm x 15° abutments after testing

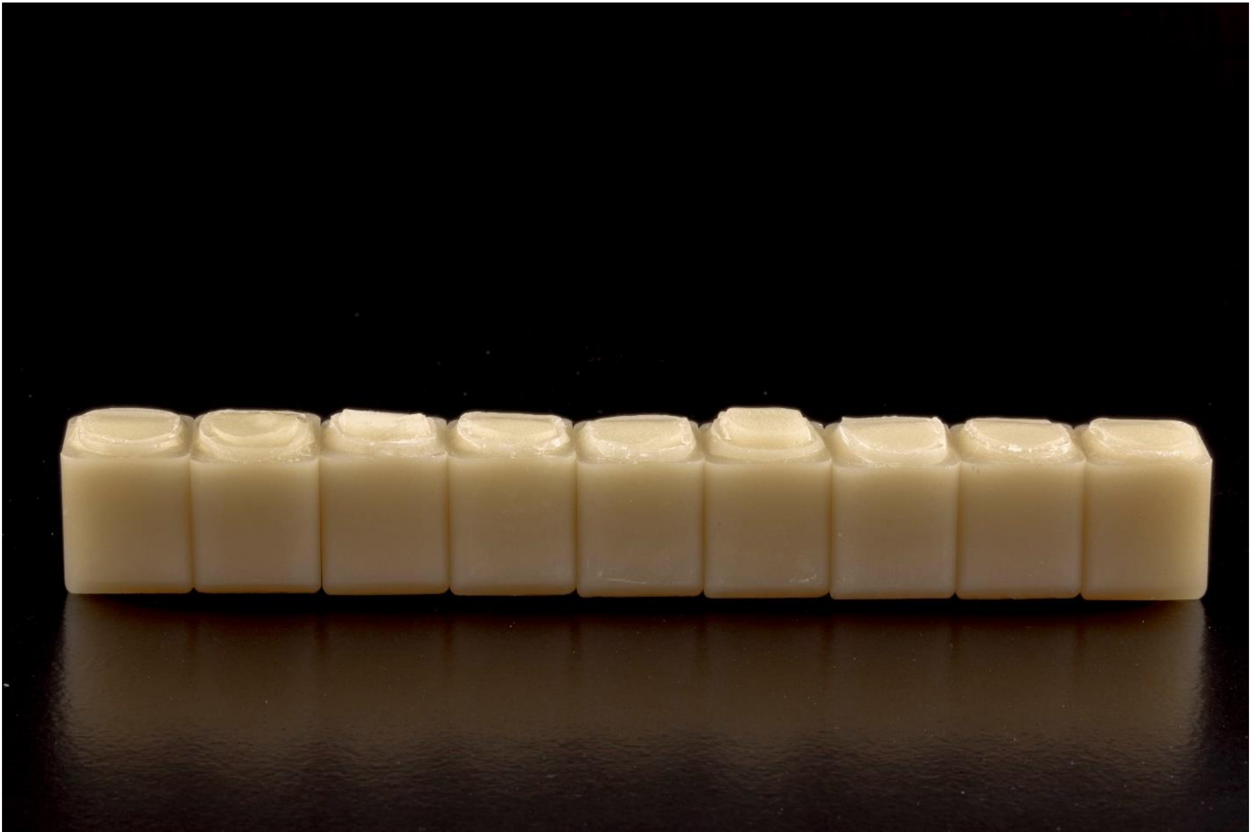

Figure 11: 2 mm x 7° abutments after testing

Figure 12: 2 mm x 15° abutments after testing

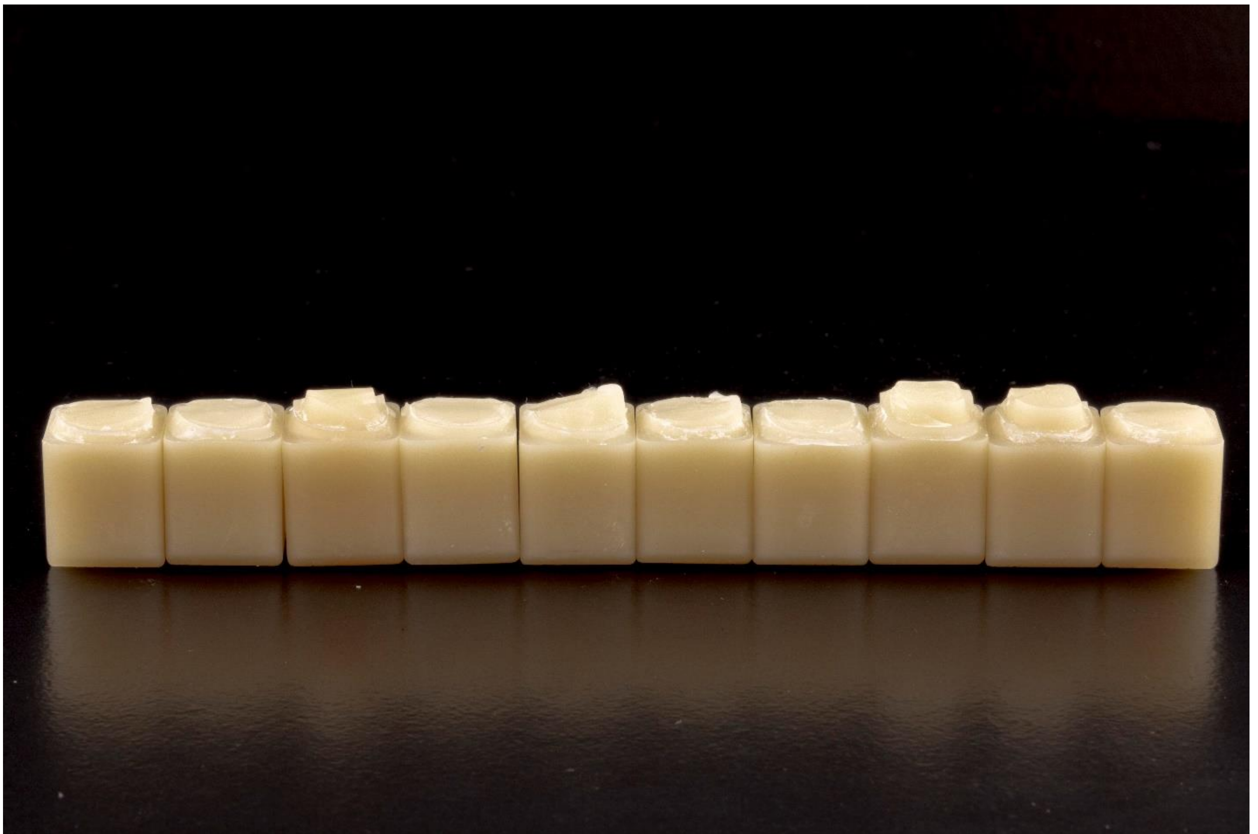

Figure 13: 3 mm x 7° abutments after testing

Figure 14: 3 mm x 15° abutments after testing

Figure 15: 4 mm x 7° abutments after testing

Figure 16: 4 mm x 15° abutments after testing

RAW DATA

Table 6: Load at break for 1 mm axial wall samples

	Load at Break [N]	Compressive extension at Break [mm]		Load at Break [N]	Compressive extension at Break [mm]
1 mm x 7 degrees			**1 mm x 15 degrees**		
1	1100.28540	0.64364	1	1251.72144	0.35166
2	1219.37097	0.43513	2	325.31769	0.03673
3	1814.02710	0.61021	3	1272.43555	1.16805
4	1620.50720	0.50575	4	1253.84924	0.84311
5	1245.92627	0.56966	5	1161.00159	0.51344
6	1563.81580	0.55180	6	1368.40198	0.48415
7	1405.13928	0.51391	7	1293.41785	0.36623
8	1176.71643	0.35748	8	1209.19946	0.43933
9	1124.09888	0.35958	9	1297.04028	0.37315
10	2207.44458	0.44497	10	-	-
SD	327.66873	0.09010	SD	317.99837	0.32367

Table 7: Load at break for 2 mm axial wall samples

	Load at Break [N]	Compressive extension at Break [mm]		Load at Break [N]	Compressive extension at Break [mm]
2 mm x 7 degrees			**2 mm x 15 degrees**		
1	1748.13721	0.40035	1	1532.71704	0.73276
2	1658.73621	0.59015	2	1606.82947	1.08339
3	1419.37732	0.49316	3	1139.62439	0.65354
4	1889.87854	0.54366	4	927.90869	0.64772
5	1854.76990	0.53371	5	1918 .98047	0.51455
6	1819.24548	0.55074	6	1704.84485	0.55277
7	2115.33765	0.49203	7	1755.85156	0.82355
8	1996.97021	0.53388	8	1568.84937	0.43238
9	1622.39673	0.42079	9	1746.02722	0.50529
10	1967.15588	0.49516	10	1543.72449	0.41927
SD	204.35256	0.05864	SD	298.13404	0.20340

Table 8: Load at break for 3 mm axial wall samples

	Load at Break [N]	Compressive extension at Break [mm]		Load at Break [N]	Compressive extension at Break [mm]
3 mm x 7 degrees			**3 mm x 15 degrees**		
1	1416.05139	0.61041	1	1574.41943	0.60807
2	1592.25317	0.59845	2	1435.71643	0.61039
3	1129.31433	0.56554	3	1584.94409	0.57898
4	1707.84741	0.57546	4	1312.89807	0.52936
5	1621.74707	0.55443	5	1676.00061	0.60191
6	1017.01471	0.41538	6	1642.06470	0.61730
7	1284.47119	0.45566	7	1304.92749	0.62406
8	1745.39832	0.47826	8	1782.62585	0.61387
9	1372.19128	0.55732	9	1255.72974	0.45604
10	1161.20129	0.64259	10	1533.01807	0.75768
SD	256.32633	0.07264	SD	176.60163	0.07621

Table 9: Load at break for 4 mm axial wall samples

	Load at Break [N]	Compressive extension at Break [mm]		Load at Break [N]	Compressive extension at Break [mm]
4 mm x 7 degrees			**4 mm x 15 degrees**		
1	1387.00903	0.75772	1	1617.97107	0.82900
2	1856.76062	0.46346	2	1762.91907	0.99170
3	1365.52600	0.41714	3	842.05865	0.58757
4	1116.34583	0.38078	4	2017.77966	0.59197
5	1564.11084	0.38884	5	1334.84302	0.47250
6	1605.16504	0.35756	6	1824.48181	0.58922
7	1317.70825	0.34275	7	1521.20447	0.48540
8	1186.15027	0.50187	8	1320.98938	0.39343
9	708.85272	0.26721	9	1907.22644	0.41776
10	12.75241	0.40875	10	1472.70715	0.43387
SD	522.89999	0.13240	SD	345 .92120	0.19286

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