Influence of Screw Channel Angulation on the Fracture Resistance of Zirconia Abutments: An In Vitro Study

Running title: ASC on Zirconia Abutments Fracture Resistance

Sabrina Garcia-Hammaker, DDS, MS[1], Berna Saglik, DDS, MS[2], Marianella Sierraalta, DDS, MS[3], and Michael Razzoog, DDS, MS, MPH[4]

[1]Clinical Assistant Professor, Biologic and Materials Sciences & Prosthodontics, University of Michigan School of Dentistry, Ann Arbor, MI

[2]Clinical Associate Professor, Biologic and Materials Sciences & Prosthodontics, University of Michigan School of Dentistry, Ann Arbor, MI

[3]Clinical Professor, Biologic and Materials Sciences & Prosthodontics, University of Michigan School of Dentistry, Ann Arbor, MI

[4]Professor, Biologic and Materials Sciences & Prosthodontics, University of Michigan School of Dentistry, Ann Arbor, MI

Corresponding author:

Sabrina Garcia Hammaker, DDS, MS

University of Michigan School of Dentistry

1011 N. University Ave., #1020

Ann Arbor, MI 48109

This is the author manuscript accepted for publication and has undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1111/jopr.13275.

samireth@umich.edu

Funding: This study was supported in part by the Dental Master's Thesis Award, Delta Dental Foundation, Farmington Hills, MI.

Conflict of interest: None

Accepted date October 9, 2020

ABSTRACT

Purpose: The aim of this study was to investigate the effect of implant screw channel angulation on the fracture resistance of zirconia abutments without artificial aging.

Materials and Methods: Ten implant replicas were embedded in a jig of autopolymerizing acrylic resin. Using a surveyor and a metallic platform, the implant replicas were mounted centrally and with an angulation of 30 degrees. A maxillary left central incisor crown was fabricated from pattern resin and scanned. The digital design of a monolithic zirconia implant abutment-crown was completed using a 3D imaging software. For all specimens of this group (ASC_{25}), the screw channel was positioned at 25 degrees to the lingual. Following fabrication, the samples were attached onto the embedded implant replicas and manually torqued to 35 Ncm as recommended by the manufacturer. The monolithic zirconia implant abutment-crowns were mounted in a metallic platform, positioned perpendicular to the indenter, and subjected to loading until failure. Crosshead speed was set at 0.5 mm/min for the universal testing machine. Data from a similar in-vitro study where straight zirconia custom abutments (ASC_0) were subjected to static load until failure was used as a control group. An unpaired Student's t-test was used to determine if fracture resistance based on load at failure and maximum load in each group were significantly different from each other (ASC_{25} vs. ASC_0). Statistical significance level was inferred at $P \leq .05$

Results: Group ASC_{25} fractured at a mean (SD) load of 215.49 (47.10) N and a mean (SD) maximum load of 420.50 (17.18) N. Group ASC_0 fractured at a mean (SD) load of 534.04 (133.77) N and a mean (SD) maximum load of 762.69 (109.59) N. The difference was statistically significant for both mean load and mean maximum load at failure ($P \leq .05$). The survival rate of 0 degrees zirconia abutments was significantly higher than that of 25 degrees ASC zirconia abutments.

Conclusions: Within the limitations of this in vitro study the mean fracture load was significantly higher in the group with a straight channel angulation.

Keywords: two-piece abutments; zirconia abutments; fracture; angulated screw channel; anterior restorations

The advancements in implant-supported prosthetics translate nowadays in making the most of a patient's esthetic and functional demands. It involves, from an interdisciplinary standpoint, the determination of both the surgeon and the restorative dentist to create the appearance of a natural tooth where an implant has been placed, hopefully in the ideal position.[1] Implant position in the anterior maxilla usually represents a difficult situation when the implant is not ideally placed in the resorbed alveolar bone. A custom-made zirconia abutment can compensate for the degrees of variation during the placement of an implant in the esthetic zone while maintaining the morphological features of the soft tissue and the overlying crown.[2] The definitive restoration may be either cemented or screw retained onto the abutment, and even though each technique has its advantages and disadvantages, the method of retention of the implant crown appears to be influenced by the clinician predilection.[3-5]

However, the latest advances in restorative dentistry allow the screw-retained restorations to offer esthetic, functional, and biological outcomes very similar to those offered by cement-retained restorations, providing the opportunity of easy retrievability as well as diminishing the risk of leaving behind residual cement. Nonetheless, there are cases in which screw retention is still not an option because the screw access would interfere with the esthetics. In these situations, cement-retained restorations are preferred because they can accommodate more implant positions.[6-8] With the introduction of the Angulated Screw Channel (ASC) zirconia abutment the management of clinical situations with screw-retained restorations, where the access hole location interferes with the esthetics, seems more attainable. The design of the ASC allows the clinician to place the screw access hole anywhere between 0 to up to 25 degrees in a 360-degree radius from the axis of the implant.[8] Several studies[9-11] and clinical reports[12] have been recently presented advocating for the use of ASC abutments. Friberg and Ahmazdai[9] tested ASC in single tooth situations of the anterior maxilla. The study followed up 51 implants placed in maxillary incisors or canine area restored with ASC zirconia abutments framework with porcelain veneer restorations. A total of 42 implants out of 49 required ASC abutments, based on surgical technique due to bone availability and probably laboratory technician design considerations. Another prospective study was presented by Pol et al[10] with ASC in the posterior region for single-tooth molar rehabilitation. This prospective study consisted of 30 implants placed in the posterior maxilla and mandible followed by restoration with full contour zirconia restorations with ASC abutments. Regardless of the position of the implants and the design of the restoration, both studies reported similar results in terms of restoration performance after one year in function (100% success rate) and implant survival rate (98% and 100%).

Regardless of zirconia's high elastic modulus (215 GPa) and flexural strength (>1000 MPa), it is still vulnerable to tensile forces and prone to fracture, especially when thin sections of the material are located in high-stress areas.[13] Its fracture resistance has been studied by several in vitro experiments but inconsistencies in the study design make it difficult to correlate conclusions related to the fracture strength of the material.[2, 14] Potential factors are the type of implant-abutment connection, angle and point of loading, and abutment design.[2] Thulasidas et al[2] concluded that lingually orienting the apical portion of the implant considerably decreased the fracture strength of zirconia abutments.

The use of a monolithic or two-piece design with zirconia cemented to a metallic sleeve surrounding the connecting interface to the implant also needs to be considered.[15-23]

Despite the fact that literature presents several studies that evaluate the average fracture load of zirconia abutments under numerous loading situations and angulations, little has been investigated regarding the effects of varied screw channel angulation on the fracture resistance of zirconia abutments. The null hypothesis is that there is no significant effect in zirconia abutment load to fracture strength without artificial aging when screw channel angulation is varied.

MATERIALS & METHODS

A current review of the dental literature revealed no studies regarding the influence of screw channel angulation on the fracture resistance of zirconia. Based on this, a power analysis of existing data from a previous study by Thulasidas et al[2] was performed to determine the appropriate sample size for this in vitro study. In order to demonstrate statistically significant differences ($P \leq .05$) of fracture resistance of zirconia abutments with 2 different screw channel angulations by 90% probability, a sample size of ten specimens per group (n=10) was found to be sufficient.

Ten implant replicas (Conical Connection RP 36698; Nobel Biocare, Yorba Linda, CA) were embedded, in a cube of autopolymerizing acrylic (Caulk Orthodontic Resin; Dentsply Caulk, York, PA) with dimensions of 3 × 3 × 3 cm^3. Each replica was held in position with a guide pin (Implant Level Conical Connection RP/WP and External Hex RP 30 mm; Nobel Biocare, Yorba Linda, CA) and attached to a laboratory surveyor (Ney Surveyor Parallometer System; Dentsply Neytech, York, PA). The surveyor was used as an instrument to systematize the affixing of the implant replicas into the acrylic jigs. Each jig was mounted in a metallic platform, previously positioned under the surveyor and adjusted at 30 degrees relative to the vertical arm of the surveyor and the mechanical indenter of the universal testing machine (Model 5566; Instron Corporation, Norwood, MA) (Fig. 1). This represented the off-axis loading between the central incisor crown supported by the implant and the universal testing machine applicator simulating the mandibular incisor. The implant replicas were mounted centrally and with an angulation of 30 degrees. Autopolymerizing acrylic resin was used to fix implant analogs into the acrylic resin holders and was let undisturbed for over 24 hours to allow complete polymerization.

Based on the anatomic average[24], a maxillary left central incisor crown was fabricated from pattern resin (Pattern Resin LS; GC America Inc., Alsip, IL). A 1.5 mm contact platform was created parallel to the surface of the jig and 2 mm below the incisal edge in the mesiodistal lingual surface of the pattern resin crown for the testing machine indenter. The pattern resin was scanned with a surface scanner (NobelProcera 2G Scanner; Nobel Biocare, Yorba Linda, CA) (Fig. 2). The digital design of the monolithic zirconia implant abutment-crown was completed using a 3D imaging software (NobelProcera 3D GUI; Nobel Biocare, Yorba Linda, CA). For all specimens of Group ASC_{25}, the screw channel was positioned at 25 degrees to the lingual (Fig. 3). The scanned data was communicated electronically to the manufacture facility (Nobel Biocare, Mahwah, NJ) for fabrication of ten abutments. Later, the monolithic zirconia implant abutment-crowns were manually attached with a torque wrench (Omnigrip driver; Nobel Biocare, Yorba Linda, CA) onto the implant replicas in the acrylic jigs and torqued to 35 Ncm following manufacturer's recommendations. The specimens were mounted in a metallic platform, positioned perpendicular to the indenter, and subjected to loading until failure. The crosshead speed was set at 0.5 mm/min for the universal testing machine. The indenter contacted the center of the mesiodistal lingual surface in a contact width of nearly 1 mm. The force was transferred to the lingual surface of the abutment/crown ensemble 2 mm below the incisal edge. (Fig. 4) A software system (Bluehill 2 Software; Instron, Norwood, MA) was used to operate the universal testing machine and to register a stress-strain diagram and breaking loads. The data used for Group ASC_0 (Control group) was obtained from a similar in vitro study[25] where straight zirconia custom abutments (ASC_0) were subjected to static load until failure.

An unpaired Student's t-test was used to determine if fracture resistance based on load at failure and maximum load in each group were significantly different from each other (Group ASC_{25} vs. Group ASC_0). Statistical significance level was inferred at $P \leq .05$. No artificial aging was used in this in-vitro study.

RESULTS

The results of the study are presented in Table 1, which shows the descriptive statistics of load at failure and maximum load in each group. Group ASC_{25} fractured at a mean (SD) load of 215.49 (47.10) N and a mean (SD) maximum load of 420.50 (17.18) N. Group ASC_0 fractured at a mean (SD) load of 534.04 (133.77) N and a mean (SD) maximum load of 762.69 (109.59) N. The survival rate of 0 degrees zirconia abutments was significantly higher than that of 25 degrees ASC zirconia abutments. The mode of failure of the 25 degrees zirconia abutments was fracture at the apical portion of the zirconia piece of the two-piece abutment with some minor damage to the head of the screw, but without visible plastic deformations to the titanium piece or the implant replica (Figs. 5, 6) The pattern of fracture at the apical portion of the zirconia piece of eight out of ten specimens in Group 1 showed loss of continuity of the screw channel. Out of eight specimens, five showed discontinuity on the left lingual portion, and three showed discontinuity on the middle lingual portion, both in vicinity with the screw channel access. Only two specimens' pattern of fracture did not exhibit communication with the screw channel access. Regardless of the pattern of fracture exhibited, all of the specimens fractured at the most apical portion of the zirconia piece of the two-piece abutment. This corresponds to the thinnest section of zirconia of the abutment where the ceramic component meets with the metallic piece. (Fig. 7)

DISCUSSION

The hypothesis was rejected considering that the abutments revealed a significantly lower fracture resistance when the screw channel angulation was varied. The majority of the available studies on one-piece zirconia implant abutments simulated the replacement of a single incisor.[14,16,19,25]

The load bearing capacities reported in these papers range from 429 to 793 N under load angles that go from 30 to 60 degrees. A strong correlation appears to exist between calculated fracture loads and type of implant-abutment connection.[26] Following previous studies, a contact angle of 30 degrees was used.[14,16,17,19,25]

According to Ferrario et al, bite forces in healthy young male adults are 150 N for central incisors and 140 N for lateral incisors, but bite forces above average are to be anticipated in patients with parafunctional conditions.[27] In the present study, the mean fracture loads for both groups exceeded the aforementioned bite forces. The type of load in this study resembles a parafunctional situation, such as bruxism, instead of a mastication-type. Similar to previous in vitro investigations,[14,16,17,19,20,28,29] static loads were used to fracture the specimens. In this study, loads were applied with a 0.5mm/min crosshead speed, possibly tolerating much higher loads before fracture. Of the two-piece abutment, only the zirconia piece failed by fracture in all samples. This is comparable with reports published by Zandaparsa.[29] Past studies evaluating the fracture resistance of zirconia abutments have used base metal cemented crowns,[2,21,31] or no crown at all.[28,29] The test specimens in this vitro study consisted of a dental implant analog/monolithic zirconia implant abutment-crown assembly. The monolithic zirconia implant abutment-crown makes reference to the fact that the abutment was designed as a screw-retained crown, which was fabricated from pattern resin based on the anatomic average of a maxillary left central incisor.[24]

Comparable with results described by Drew and Zandaparsa, the mode of failure of all the samples was fracture at the apical segment of the ceramic piece, with no visible damage or plastic deformation of the titanium sleeve, abutment screw, or implant analog.[11,29] In previous studies,[25,28] one-piece zirconia custom abutments demonstrated lower bending forces in the area of the apical hexagon, leading to the lowest mean fracture load when compared with two-piece zirconia custom abutments. In a two-piece zirconia custom abutment, loading forces might be greater in the area where the abutment connects to the implant and where the abutment is thinner. The results of this study confirm those of previous ones related to the clinical performance of two-piece zirconia custom abutments.[11,29] In the design and fabrication of CAD/CAM one-piece or two-piece zirconia custom abutments this thickness is controlled by the manufacturer. The thickness for two-piece zirconia custom abutments in this area ranges between 0.40 and 0.60mm. Drew also reported this area to be a possible weak point of 0.432 mm in thickness.[11] The angulation of the screw channel, however, had a statistically significant and negative influence on the strength of the two-piece zirconia custom abutment. In this study, the mean fracture load for group 1 (screw channel angulated 25 degrees to the lingual) was 215.49 ±47.10 N, which is approximately 2.47 times less than its straight one-piece counterpart with a mean fracture load of 534.04 ±133.77 N.

Dental restorations should be able to withstand a wide range of forces over an extended period of time in an aqueous environment.[31,32] Based on Zandparsa and Albosefi's study, along with the results of past investigations, artificial aging was not used due to the failure to apply a statistically significant effect on the fracture resistance of straight or angulated zirconia abutments.[28,29] In spite of this, if applied it could have resulted in a decreased mean maximum applied force before failure.

Study limitations

Similar to other in vitro studies, implant analogs were secured in autopolymerizing acrylic resin.[11,20,25,30] However in the future, new results could be obtained from using another material with a modulus of elasticity and volume comparable to human alveolar bone. In an effort to establish some uniformity with methods from other studies, the experiment conducted also followed the ISO Norm 14801:2016. Although the standard it is not proposed for testing "the fundamental fatigue properties of the materials from which the endosseous implants and prosthetic components are made" the standard replicates the functional loading of the implant under "worst case" conditions.[33] Regarding the type of load used (cyclic or static), it is very difficult to replicate dynamic occlusal movements and patterns during in vitro studies. The comparison of data between studies on the fracture resistance of zirconia custom abutments is challenging because there are many variations in study design. Disparity in the angle which the load is applied, assessment methods, proportions, shape and type of abutment (one-piece vs. two-piece), final restorations, and even manufacture design will have an impact on the final results. This is an in vitro study, and although similar to previous investigations, limitations included not considering aging, using implant replicas instead of actual implants, acrylic resin as material for replica placement rather than alveolar bone surrounding an implant, use of static load to reach the fatigue failure, etc. Because the use of the ASC abutments has reached a fair level of popularity among providers in the past couple of years, additional in vitro studies without these limitations are required to evaluate all the available systems under simulated clinical conditions. Moreover, in vivo studies considering the type and quality of zirconia used, technique of fabrication, and different manufacturers' workflow are recommended to offer a definitive conclusion of the clinical performance of this type of abutments.

Modification of the screw channel angulation has an effect on the fracture resistance of two-piece zirconia custom abutments; however natural occlusal forces are below the range of fracture load showed in this experiment. Results show that this type of abutment can be used for implant rehabilitation in the anterior zone where screw-retained restorations are desired or indicated, without compromising the esthetics of the selected treatment.

CONCLUSIONS

Within the limitations of this in vitro study, it is concluded that two-piece zirconia custom abutments failed by fracture in both groups with several screw channel angulations, but the mean fracture load was significantly higher in the group with a straight channel angulation. The following conclusions can be made:

1. Mean fracture load of straight two-piece zirconia custom abutment until failure was 2.4 times that of the 25 degrees to the lingual zirconia abutment group.

2. The maximum load before failure for the straight channel group was almost twice (1.8) that of the angulated screw channel abutment group.
3. Without considering fatigue loading, specimens in both groups failed at loads that exceeded the physiologic range.

ACKNOWLEDGMENTS

Thank you to the Delta Dental Foundation for the financial support and to Mr. Rui-Feng Wang for his time and collaboration performing all the statistic work of this research project.

REFERENCES

1. Lazzara RJ: Immediate implant placement into extraction sites: Surgical and restorative advantages. Int J Periodontics Restorative Dent 1989;9:332-343

2. Thulasidas S, Givan DA, Lemons JE, et al: Influence of implant angulation on the fracture resistance of zirconia Abutments. J Prosthodont 2015;24:127–135

3. Chee W, Jivraj S: Screw versus cemented implant supported restorations. Evid Based Dent 2006;201:501–507

4. Dario LJ: Implant angulation and position and screw or cement retention: Clinical guidelines. Implant Dent 1996;5:101-104

5. Michalakis KX, Hirayama H, Garefis PD: Cement-retained versus screw-retained implant restorations: A critical review. Int J Oral Maxillofac Implants 2003;18:719–728

6. Priest G: A current perspective on screw-retained single-implant restorations: A review of pertinent literature. J Esthet Restor Dent 2017;29:161-171

7. Hebel KS, Gajjar RC: Cement-retained versus screw-retained implant restorations: Achieving optimal occlusion and aesthetics in implant dentistry. J Prosthet Dent 1997;77:28–35

8. Garcia-Gazaui S, Razzoog M, Sierraalta M, et al: Fabrication of a screw-retained restoration avoiding the facial access hole: A clinical report. J Prosthet Dent 2015;114:621-624

9. Friberg B, Ahmadzai M: A prospective study on single tooth reconstructions using parallel walled implants with internal connection (NobelParallel CC) and abutments with angulated screw channels (ASC). Clin Implant Dent Relat Res. 2019;21:226–231

10. Pol CWP, Raghoebar GM, Maragkou Z, et al: Full-zirconia single-tooth molar implant-supported restorations with angulated screw channel abutments: A 1-year prospective case series study. Clin Implant Dent Relat Res 2019;1–7

11. Drew A, Randi A, DiPede L, Luke A: Fracture strength of implant screw-retained all-ceramic crowns with the use of the angulated screw channel: A pilot study. Int J Period Rest Dent 2020;40:245-252

12. Gjelvold B, Sohrabi MM, Chrcanovic BR: Angled Screw Channel: An Alternative to Cemented Single-Implant Restorations—Three Clinical Examples. Int J Prosthodont 2016;29:74–76

13. Wang H, Aboushelib MN, Feilzer AJ: Strength influencing variables on CAD/CAM zirconia framework. Dent Mater 2008;24:633-638

14. Yildirim M, Fischer H, Marx R, et al: In vivo fracture resistance of implant supported all-ceramic restorations. J Prosthet Dent 2003;90:325-331

15. Velázquez-Cayón R, Vaquero-Aguilar C, Torres-Lagares D, et al: Mechanical resistance of zirconium implant abutments: A review of the literature. Med Oral Patol Oral Cir Bucal 2012;17:246-250

16. Aramouni P, Zebouni E, Tashkandi E, et al: Fracture resistance and failure location of zirconium and metallic implant abutments. J Contemp Dent Pract 2008;9:41-48

17. Kerstein RB, Radke J: A comparison of fabrication precision and mechanical reliability of two zirconia implant abutments. Int J Oral Maxillofac Implants 2008;23:1029-1036

18. Lughi V, Sergo V: Low temperature degradation -aging- of zirconia: A critical review of the relevant aspects in dentistry. Dent Mater 2010;26:807-820

19. Adatia ND, Bayne SC, Cooper LF: Fracture resistance of yttria-stabilized zirconia dental implant abutments. J Prosthodont 2009;18:17-22

20. Nothdurft FP, Doppler KE, Erdelt KJ, et al: Fracture behavior of straight or angulated zirconia implant abutments supporting anterior single crowns. Clin Oral Invest 2011;15:157-163

21. Sailer I, Sailer T, Stawarczyk B, et al: In vitro study of the influence of the type of connection on the fracture load of zirconia abutments with internal and external implant-abutment connections. Int J Oral Maxillofac Implants 2009;24:850-858

22. Turp V, Tuncelli B, Sen D, et al: Evaluation of hardness and fracture toughness, coupled with microstructural analysis of zirconia ceramics stored in environments with different pH values. Dent Mater 2012;31:891-902

23. Sherif S, Susarla H, Kapos T, et al: A systematic review of screw-versus cement-retained implant-supported fixed restorations. J Prosthodont 2014;23:1–9

24. Magne P, Gallucci GO, Belser UC: Anatomic crown width/length ratios of unworn and worn maxillary teeth in white subjects. J Prosthet Dent 2003;89:453-461

25. Katsavochristhou N, Sierraalta M, Saglik B, et al: Implant Angulation Effect on the Fracture Resistance of Monolithic Zirconia Custom Abutments: An In Vitro Study. J Prosthodont 2019 Nov 19. doi: 10.1111/jopr.13127

26. Sailer I, Philipp A, Zembie A, et al: A systematic review of the performance of ceramic and metal implant abutments supporting fixed implant reconstructions. Clin Oral Implants Res 2009;20:4-31

27. Ferrario VF, Sforza C, Serrao G, et al: Single tooth bite forces in healthy young adults. J Oral Rehabil 2004;31:18-22

28. Albosefi A, Finkelman M, Zandparsa R: An in vitro comparison of fracture load of zirconia custom abutments with internal connection and different angulations and thickness: part I. J Prosthodont 2014;23:296-301

29. Zandparsa R, Albosefi A: An In Vitro Comparison of Fracture Load of Zirconia Custom Abutments with Internal Connection and Different Angulations and Thicknesses: Part II. J Prosthodont 2016;25:151-155

30. Foong JK, Judge RB, Palamara JE, et al: Fracture resistance of titanium and zirconia abutments: an in vitro study. J Prosthet Dent 2013;109:304-312

31. Denry I, Kelly JR: State of the art of zirconia for dental applications. Dent Mater 2008;24:299-307

32. Truninger TC, Stawarczyk B, Leutert CR, et al: Bending moments of zirconia and titanium abutments with internal and external implant-abutment connections after aging and chewing simulation. Clin Oral Implants Res 2012;23:12-18

33. International Organization for Standardization: Dentistry-implants-dynamic loading test for endosseous dental implants. ISO 14801:2016 (E)

TABLE

Table 1. The descriptive statistics of Load at Failure and Maximum Load of each group

in N	Group	n	Mean	Variance	SD	P-Value
Load at Failure	ASC_{25}	10	215.49	2218.61	47.10	<.0001
	ASC_0	15	534.05	17895.88	133.78	
Maximum Load	ASC_{25}	10	420.51	295.48	17.19	<.0001
	ASC_0	15	762.70	12011.93	109.60	

FIGURE LEGENDS

Figure 1. Surveyor and platform assembly for mounting of implant replica

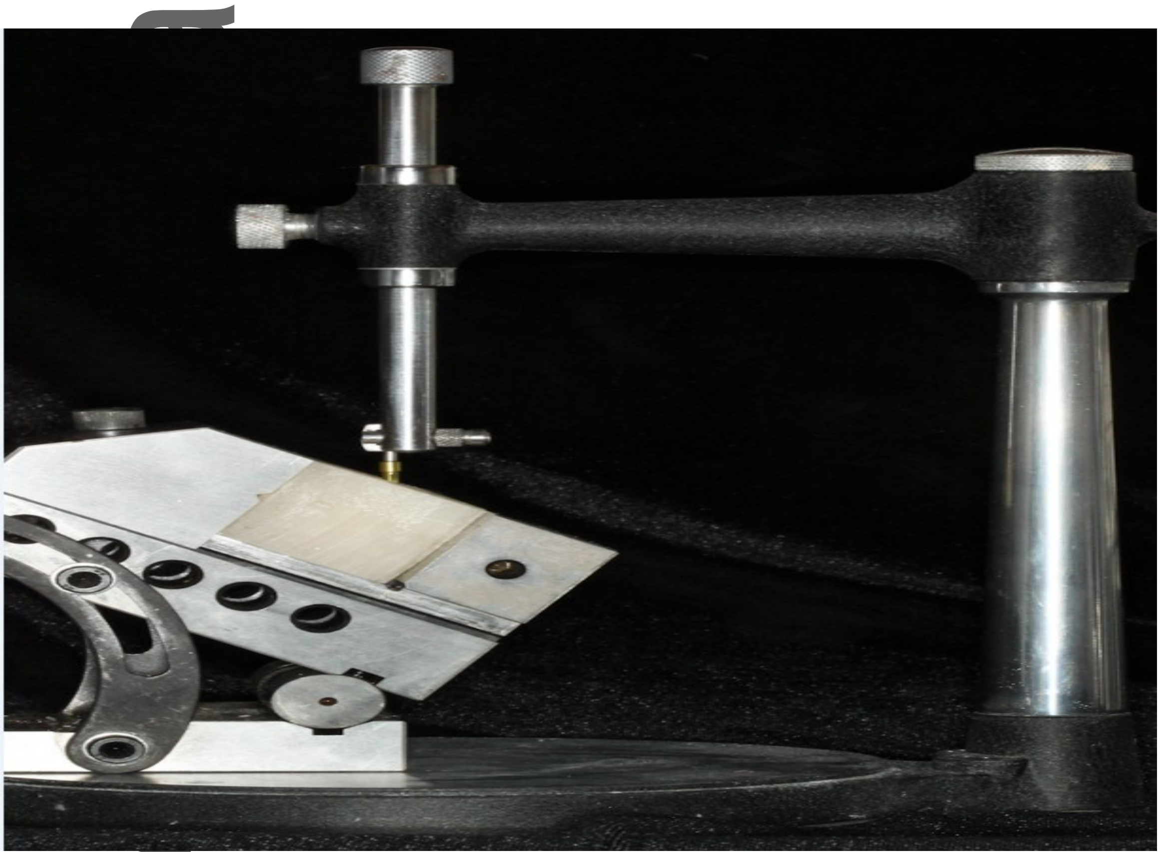

Figure 2. Pattern resin during scanning process

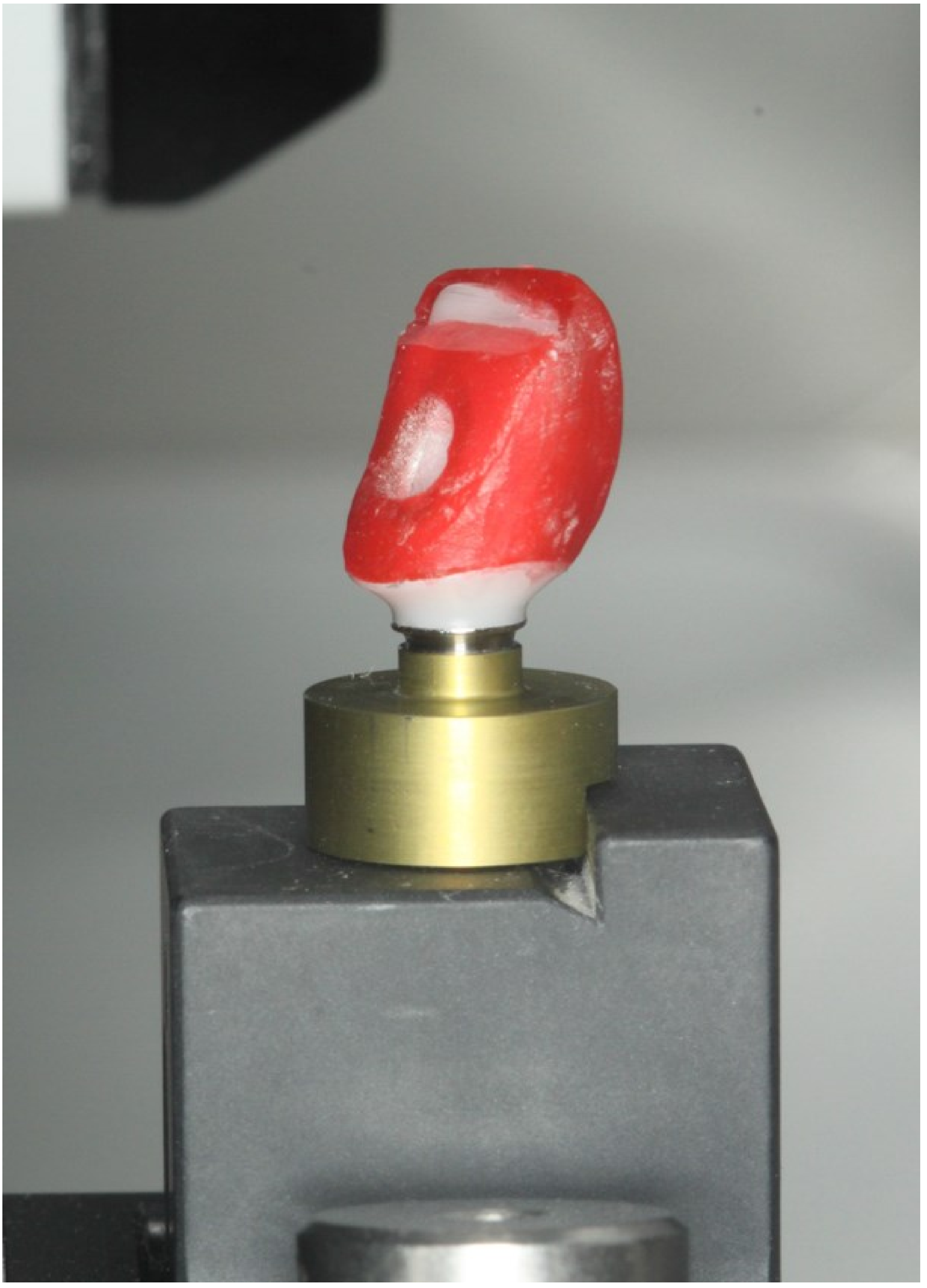

Figure 3. Screenshot during digital design of abutments with 25L

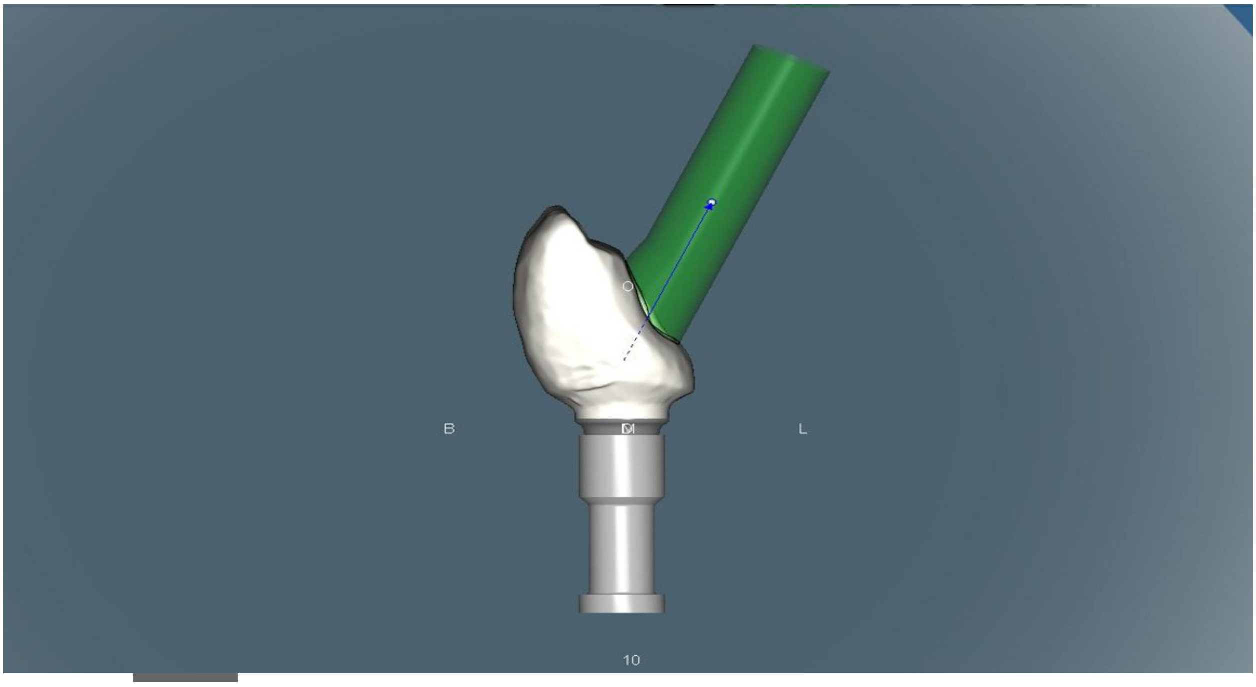

Figure 4. Instron machine and assembly

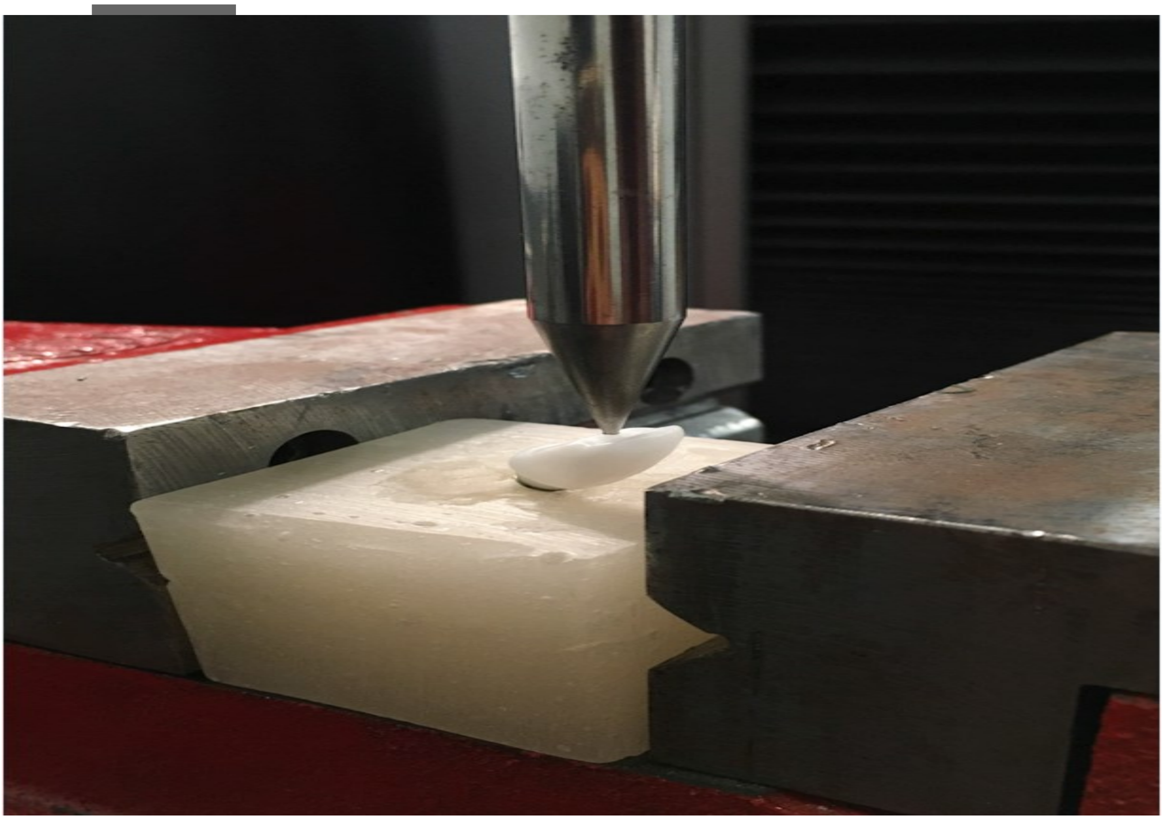

Figure 5. Mode of failure of Group ASC_{25} after loading. (A) Note titanium piece of the abutment apparently intact and still attached to implant replica by the abutment screw. (B) Scratching is noticed on abutment screw head

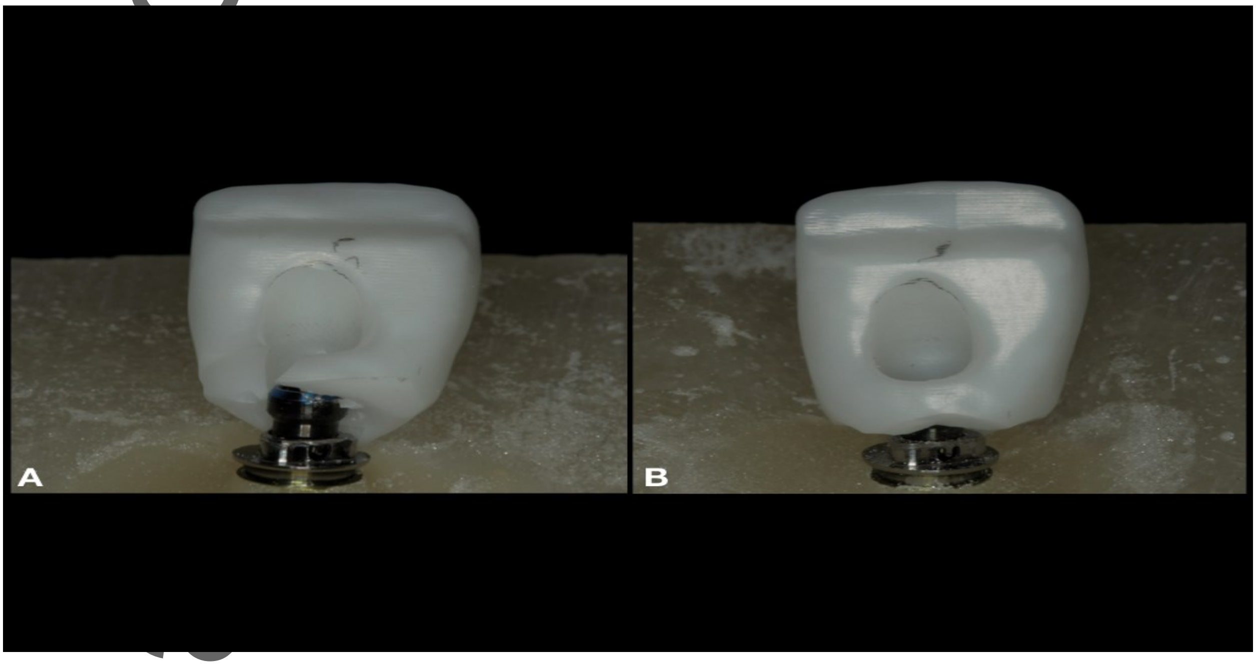

Figure 6. Group ASC_{25} specimen

Figure 7. Diagram showing thickness at apical portion of ceramic component of two-piece abutment