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IN VITRO COMPARISON OF FRACTURE AND FATIGUE RESISTANCE BETWEEN IMPLANT-SUPPORTED RESTORATIONS UTILIZING CAD/CAM SYSTEM ON A TIBASE ABUTMENT

A manuscript

Presented to the Faculty of the Advanced Education in General Dentistry, Two-Year Program,

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And the Uniformed Services University of the Health Sciences – Post Graduate Dental College

In Partial Fulfillment of the Requirements for the Degree of

Master of Science in Oral Biology

By

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April 2020

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DEDICATION

To my family, thank you for your endless love and encouragement to go for my dreams. Thank you for allowing me time away from you all to focus on the residency. I owe my academic accomplishments to you.

The author hereby certifies that the use of any copyrighted material in the thesis manuscript entitled:

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Abstract

In vitro comparison of fracture and fatigue resistance between implant-supported restorations utilizing CAD/CAM system on a TiBase abutment

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Introduction: Dental implants have become a popular and effective way to replace missing teeth. Following osseointegration, a crown can be secured on an abutment which can be seated on the implant. With the advent of the Sirona TiBase, the clinician is able to integrate digital designs to restore dental implants. This system along with the CAD/CAM technology is becoming a key component of the dental clinical workflow, facilitating same-day placement of an indirect restoration. There is limited evidence supporting the use and long-term success of TiBase restorations in the posterior region.

Objective: To evaluate the effect of *in vitro* cyclic fatigue on the fracture resistance and survival of three commonly-used restorative materials, eMax CAD, Zirconia and Enamic, cemented to TiBase hybrid abutments.

Methods: Molar-shaped implant crowns were fabricated from three CAD/CAM materials: Lithium disilicate (eMax CAD, Ivoclar Vivadent, Amherst, NY), Zirconia (inCoris Zi meso, Dentsply-Sirona, York, PA) and Enamic (Vita Enamic IS CAD, Vita North America). These crowns were cemented onto a Tibase abutment and secured on a dental implant (Nobel Biocare). The dental implants were imbedded into an orthodontic resin (Dentsply Caulk) to simulate an osseointegrated implant. The samples were subjected to a fracture test and cyclic loading by a universal testing machine (Instron).

Results: Failure of the Zirconia crowns was above the load cell of the Instron machine. Thus the Zirconia group was eliminated from the study. The difference in static load of eMax and Enamic crowns was not significant. Statistically, the fatigue strength of eMax was significantly greater than Enamic. No Tibase abutments failed.

Conclusion: All three ceramic materials cemented to a TiBase withstood forces greater than those observed in human dentition. Fatigue loading reduced the strength of the ceramics. It can be accepted that eMax, Enamic or Zirconia may be used to restore implants in posterior dentition.

TABLE OF CONTENTS

Abstract vi

List of Figures viii

Background 1

Methods and Materials 3

Results 9

Discussion 12

Conclusion 14

References 15

LIST OF FIGURES

Figure 1 Implant resin block sample with an anti-rotational depression**Error! Bookmark not defined.**

Figure 2 Components of the hybrid crown..................**Error! Bookmark not defined.**

Figure 3 Digital proposal of the CAD hybrid crown....**Error! Bookmark not defined.**

Figure 4 Fatigue testing at 0° to the long axis of the implant...................................... 7

Figure 5 Fatigue Plot for eMax CAD crowns. 8

Figure 6 Fatigue Plot for Enamic IS crowns 8

Figure 7 eMax crown failure due to catastrophic fracture 9

Figure 8 Debonded Zirconia crown.. 9

Figure 9 Plotted Static Load and Endurance Limit of eMax CAD vs Enamic IS 10

Figure 10 Probability of survival of eMax vs Enamic. 11

Figure 11 Probability of Failure of eMax vs Enamic 11

Background

Dental implants have become a popular and effective way to replace missing teeth. Following osseointegration, a crown can be secured on an abutment which can be seated on the implant. A crown can be either cemented or screw-retained. A screwmentable solution was created where a cementable crown is designed with the addition of a screw access hole. It combines the ease of delivery of a cement retained crown and the retrievability of a screw retained restoration. Traditionally, an impression would be sent to the dental laboratory and an implant crown with a custom titanium abutment would be fabricated by a lab technician. With the advent of the TiBase, the clinician is able to integrate digital designs to restore dental implants. The TiBase system contains a titanium-base insert that fits the internal connection of an implant and a scan body. A scan body is attached to the TiBase and a chairside digital impression can be made with a CAD/CAM (computer-aided design and computer-aided manufacturing) unit. A CAD hybrid screw-retained crown or CAD hybrid abutment with a separate crown can then be digitally designed and milled. This system along with the CAD/CAM technology is becoming a key component of the dental clinical workflow. It reduces a number of clinical and laboratory steps that are often required and facilitates same-day placement of an indirect restoration. This service can improve access to care, increase clinical productivity, and promote the overall readiness posture of the military.

Esthetic drawbacks of traditional implant abutments include a visible metal line along the gingiva and/or a gray hue through the ceramic restorations[1]. An alternative initially selected to address this concern was use of abutments made of Zirconia, a white ceramic material. Zirconia abutments commonly produced more favorable esthetic outcomes than metal abutments while displaying comparable strength. [2] Nonetheless Zirconia abutments are prone to fractures when used with an internal implant connection [1-3]. Fractures may occur because the titanium abutment and the Zirconia have different properties [4]. In contrast, the TiBase allows for a titanium-to-titanium implant connection. To achieve the strength of titanium and the esthetics of a ceramic, a Zirconia or Lithium Disilicate coping may be fabricated and cemented to the TiBase[5]. This characterizes a hybrid abutment, which consists of a titanium insert and a veneering ceramic to hide the metal. It is important to note, when restoring traditional titanium abutments, crowns are usually delivered via intraoral cementation to the abutments. The cement is difficult to clean and

excess cement that is not removed is associated with periimplant disease. The biologic concern of traditionally fabricated abutments is chronic inflammation of the surrounding periodontal tissues. TiBase solves this issue since the prosthesis may be cemented extraorally which removes the risk of cement extrusion [2, 6]. An additional advantage is that the clinician has the flexibility to select between numerous amounts of restorative materials.

In order to fabricate a traditional titanium custom abutment, a dental lab technician must be involved, which adds time and additional cost. The provider may lose autonomy and must rely on the technician for most of the design. By utilizing chairside digital imaging less time is required and the clinician has more control with designing the TiBase restoration. The clinician may now determine the emergence profile, material thickness parameters, and other design factors[7]. Nonetheless, more potential failure modes in the implant-supported prosthesis may arise. Such modes of failure include debonding of the ceramic from the titanium base and fracture of the ceramic. Since the TiBase is prefabricated, it cannot be modified to account for manufacturer's material thickness recommendations. Particular areas of concern for minimal material thickness are near the titanium channel, as well as the cervical region where tensile forces occur at the junction of the abutment and the implant platform. Lastly as a third party implant company, weakness in the abutment screw may occur, for example screw separation or screw loosening[2-8].

Many Army Dental clinicians are beginning to integrate CAD/CAM technology into daily practice. Digital scanning is efficient and can be a more comfortable experience compared to traditional impression procedures. Use of CAD/CAM methodologies facilitates the preparation of teeth and delivery of restorations in a single appointment. Ultimately, increased access to implant restorations may improve dental wellness of service members. Studies show that TiBase restorations are a viable solution in the anterior region[8, 9]. Nonetheless there is limited evidence supporting the use and long-term success of TiBase restorations in the posterior region. This is due to the increased forces posterior teeth are subject to, ranging from 200-900 Newtons.[4]

A recent study by Hoffman[10] evaluated the forces required to fracture implant crowns from three different ceramics cemented to TiBase connectors. 60 monolithic crowns fabricated from Enamic, eMax and Zirconia were cemented to TiBase abutments (Sirona). These abutments

were connected to a dental implant (3i Biomet) and imbedded in an acrylic material. They were subject to a constant force at 45 degrees until failure. All crown materials withstood forces exceeding those encountered in human dentition. Fifty-eight percent of the failures were due to fracture of the crown. The second most common failure was due to fracture of the abutment screw (25%). No TiBase abutments failed. Hoffman noted further research on cyclic fatigue would be beneficial. Cyclic loading would better simulate clinical conditions and occlusal behaviors that a restoration may endure.

Methods and Materials

Fabrication of Implant-Resin Block:

Ninety-nine implants (Nobel Biocare Replace Select 4.3 X 13mm Dummy implants) were imbedded in Orthodontic Resin (Dentsply Caulk) with 2mm of collar exposed to simulate clinical bone loss. The dummy implants have the same titanium composition as clinical use implants, but lack the Tiunite surface treatment for implant osseointegration. The resin which houses each dummy implant were cylindrical in shape (14mm in diameter x 24mm in height). An anti-rotational depression was placed onto the side of the resin cylinder to ensure consistent placement and positional stability within the testing apparatus. The anti-rotational depression was positioned parallel to the proximal surface of the crown and its center was located 9.4mm from the cylinder's base.

Implants were split into groups based on ceramic material. Each crown's occlusal table had a semi-hemispherical concavity as a vertical stop to support the axial loading. The concavity measured 4mm in diameter and 2mm in depth.

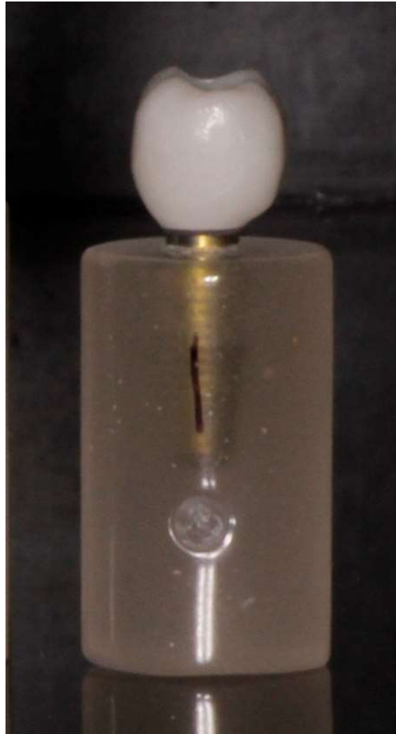

Figure 1 Implant resin block sample with an anti-rotational depression

Fabrication of CAD Hybrid Crown:

A TiBase was retained onto the implant by a screw. A ScanBody (NB RS 4.3 L, Dentsply-Sirona, York, PA) was then properly placed on the TiBase. Next, the ScanBody was imaged using the CEREC Omnicam (Dentsply-Sirona, York, PA). In turn, the hybrid screw-retained restoration/crown was designed on the CEREC Premium software (Version 4.5, Dentsply-Sirona, York, PA). From the digital proposal, three groups (33 crowns per group and a total n = 99 crowns) with identical molar anatomies were milled using a 4-axis milling unit (Sirona inLab MC XL, Dentsply-Sirona, York, PA) using three different CAD/CAM materials: Lithium Disilicate (eMax CAD, Ivoclar Vivadent, Amherst, NY), Enamic (Vita Enamic IS CAD, Vita North America) and Zirconia (inCoris Zi meso, Dentsply-Sirona, York, PA). The eMax crowns were crystallized in an Oven (Programat EP 5000, Ivoclar Vivadent, Amherst, NY) while the Zirconia crowns were sintered in a furnace (InFire HTC Speed Furnace, Dentsply-Sirona, York, PA) per manufacturer specifications. Enamic crowns did not require any further processing.

Figure 2 Components of the hybrid crown: a TiBase and a crown secured to an implant

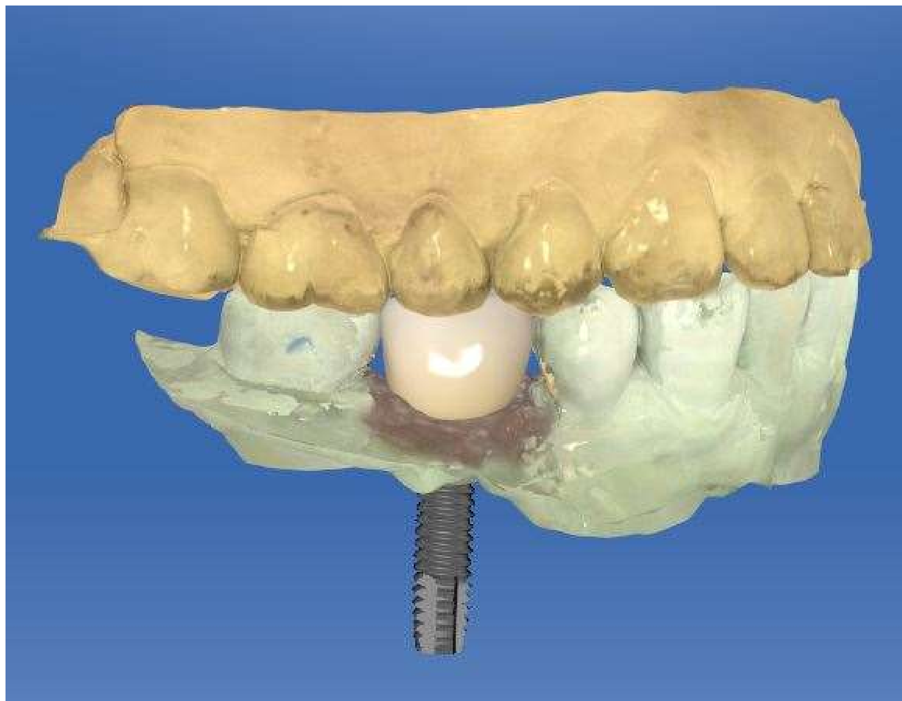

Figure 3 Digital proposal of the CAD hybrid crown

TiBase Preparation and Crown Cementation:

Each TiBase (NB RS 4.3 L, Dentsply-Sirona, York, PA) was air abraded with 50 micron aluminum oxide and 20 psi. The eMax CAD crowns were internally etched for 20 seconds with IPS Ceramic Etching Gel, 5% HFL acid (Ivoclar Vivadent, Amherst, NY). The Enamic crowns were internally etched for 60 seconds. The Zirconia crowns were air abraded. The TiBase and intaglio surface of the crowns were steam-cleaned, air dried and treated with a coupling agent (Monobond Plus, Ivoclar Vivadent, Amherst, NY) for 60 seconds. The crowns were cemented to the TiBase with Multilink Hybrid Abutment cement (Ivoclar Vivadent) according to manufacturer's instructions. After removal of excess cements, crowns were screwed into the internal connection of the implant with a torque wrench. A torque of 35NCM was applied per manufacturer recommendations. After ten minutes, the screw was retorqued to compensate for material relaxation. Teflon tape was placed in the screw channel, and bonding agent was applied (Optibond Fl, Kerr, Orange, CA). Finally, the screw hole was filled with resin-based composites (Filtek Supreme, 3M, Minneapolis, MN) and light-cured for 40 seconds.

Strength and Fatigue Evaluation:

Samples were secured in an Instron testing jig at 0° to the loading device. A universal testing machine (Model 5543, Instron, Canton, MA) applied a force to individual samples until failure. A total of eight samples of each material were tested, and results were recorded. The average value at failure were calculated.

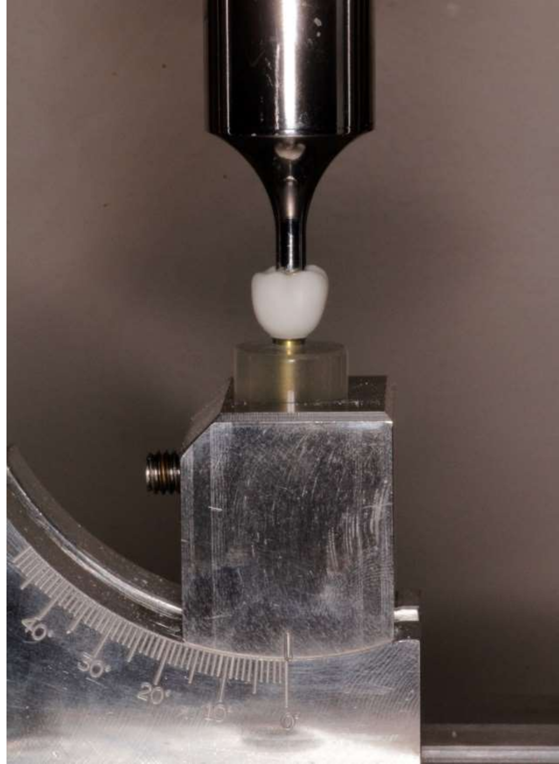

Figure 4 Fatigue testing at 0º to the long axis of the implant

A Staircase fatigue technique was used to calculate the fatigue of the remaining twenty-five samples. Half the mean load was selected for the initial staircase experiment. Duration was set at 6000 cycles and 2 hertz. The amplitude of the sinusoidal load cycles was half the standard deviation of each material's mean load. If the sample survived 6000 cycles, the next sample was tested at an interval increased by 20%. If the sample fractured, it was marked as a failure and the next experiment was completed at a reduced interval by 20%. Failures and successes were sorted by force applied. The endurance limit was calculated from the following formula[11]:

$$S_e' = \sigma_0 + d\left(\frac{A_n}{\sum n_i} \pm \frac{1}{2}\right),\ A_n = \sum i n_i$$

σ_0 is the lowest load value in the group and n_i represents the number of events (failures or successes). A positive sign was used if more tests survived, and a negative sign if more failures occurred.

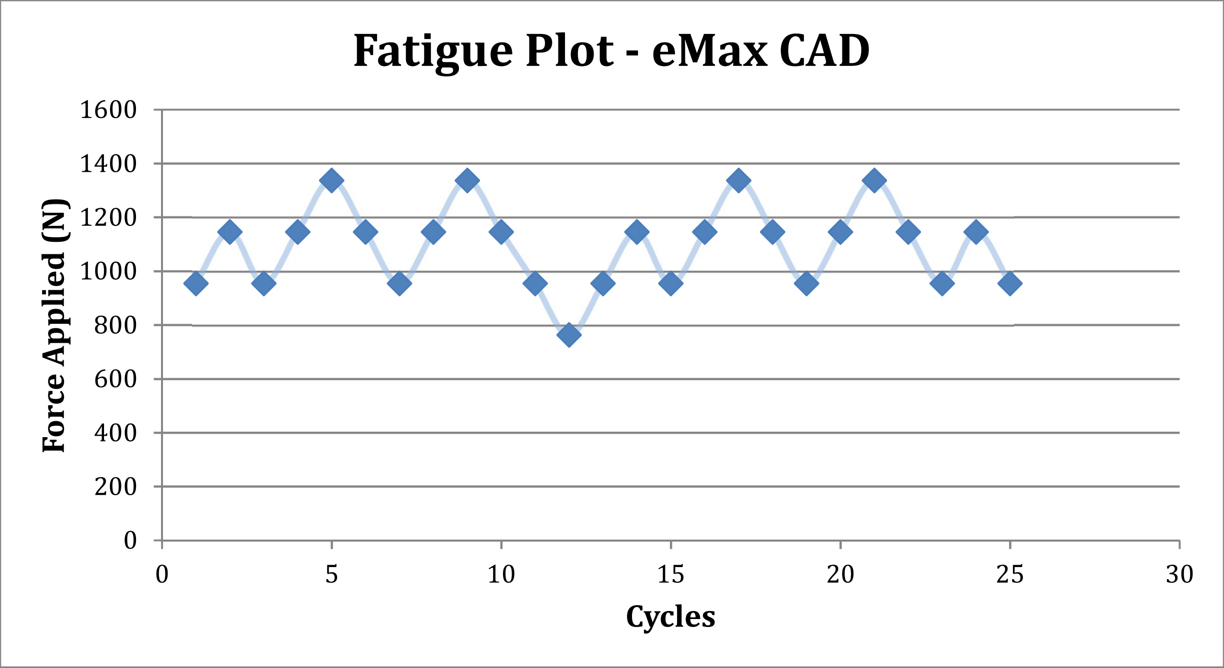

Figure 5 Fatigue Plot for eMax CAD crowns following the staircase approach

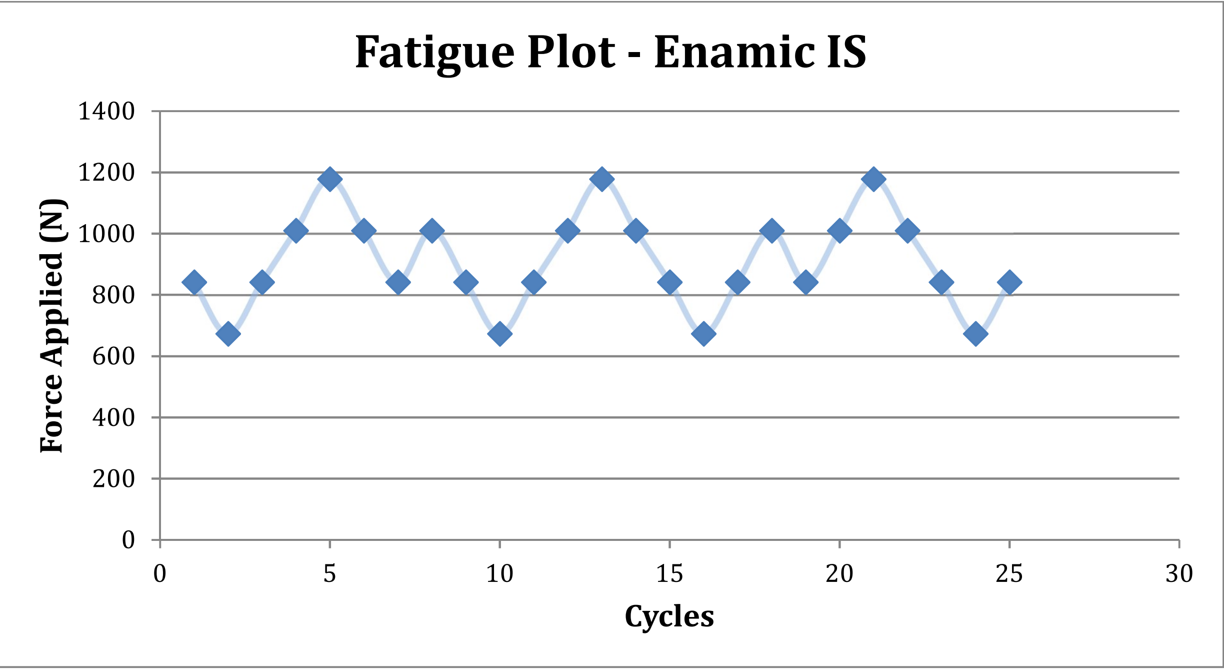

Figure 6 Fatigue Plot for Enamic IS crowns

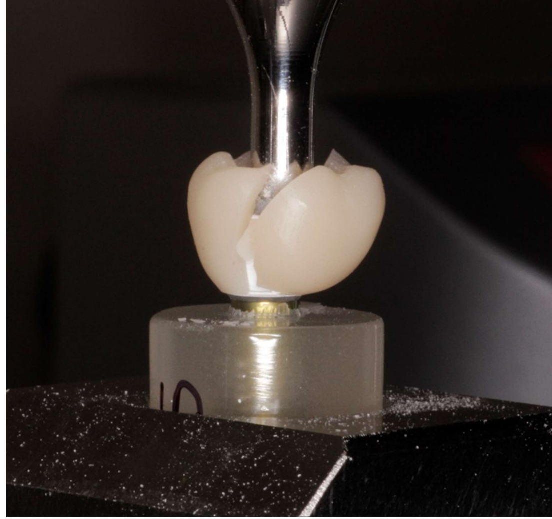

Figure 7 eMax crown failure due to catastrophic fracture

Results

A total of 66 samples were included in the analysis. Static failure of the initial eight Zirconia crowns was substantially above the load cell of the Instron machine. Thus the Staircase test was aborted and the Zirconia group (n=33) was eliminated from the study. With the forces applied, none of the Zirconia crowns fractured and at times only debonded from the TiBase. This supports that Zirconia has the highest strength and fracture resistance among the other ceramic materials. It is reliable in withstanding molar masticatory forces and is an acceptable material for a hybrid implant crown.

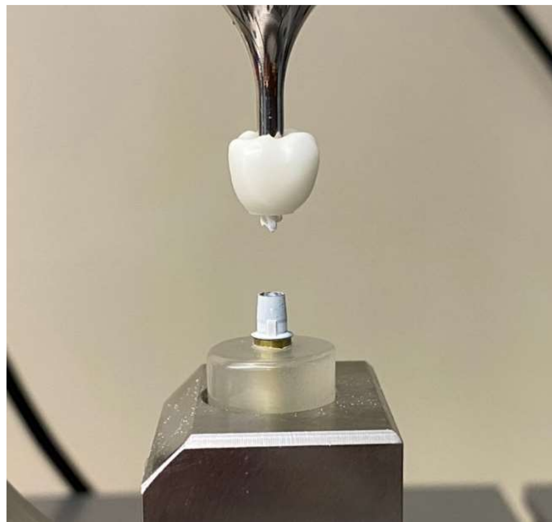

Figure 8 Debonded Zirconia crown

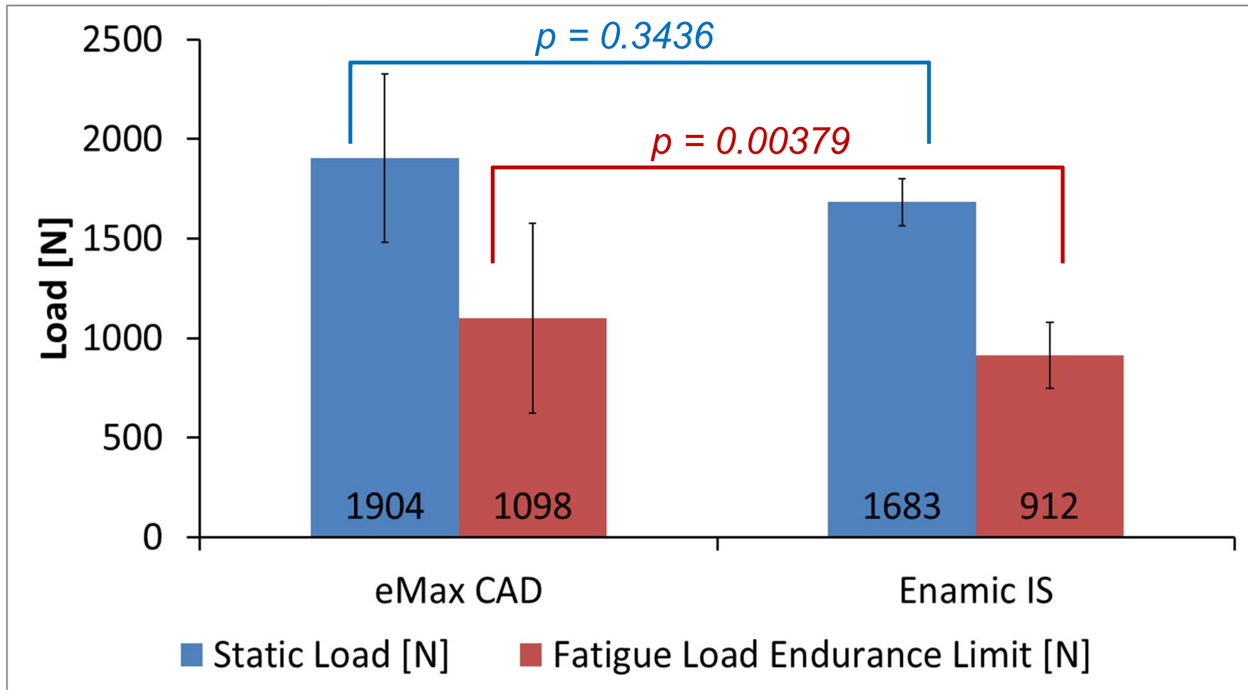

Fig 9 Static Load and Endurance Limit of eMax CAD vs Enamic IS. (P > 0.05 is not statistically significant)

The static load to failure data with mean ± SD is depicted in Figure 9. eMax showed a mean failure force of 1904N while Enamic showed a mean failure force of 1683N. eMax additionally demonstrated an endurance limit of 1098N while an endurance limit of 912N was calculated for Enamic. The endurance limit is important because it ultimately represents the material's fatigue strength, where the crown should not fracture with loads below this value.

Statistics:

Results were analyzed using a t-test. Statistically the differences in static load was not significant (P = 0.3436). However, the fatigue load of eMax was significantly greater than Enamic (P = 0.00379). On the basis of these results, the null hypothesis is rejected that there will be no significant difference in performance and survival under cyclic fatigue between the restorative materials cemented to TiBase abutments.

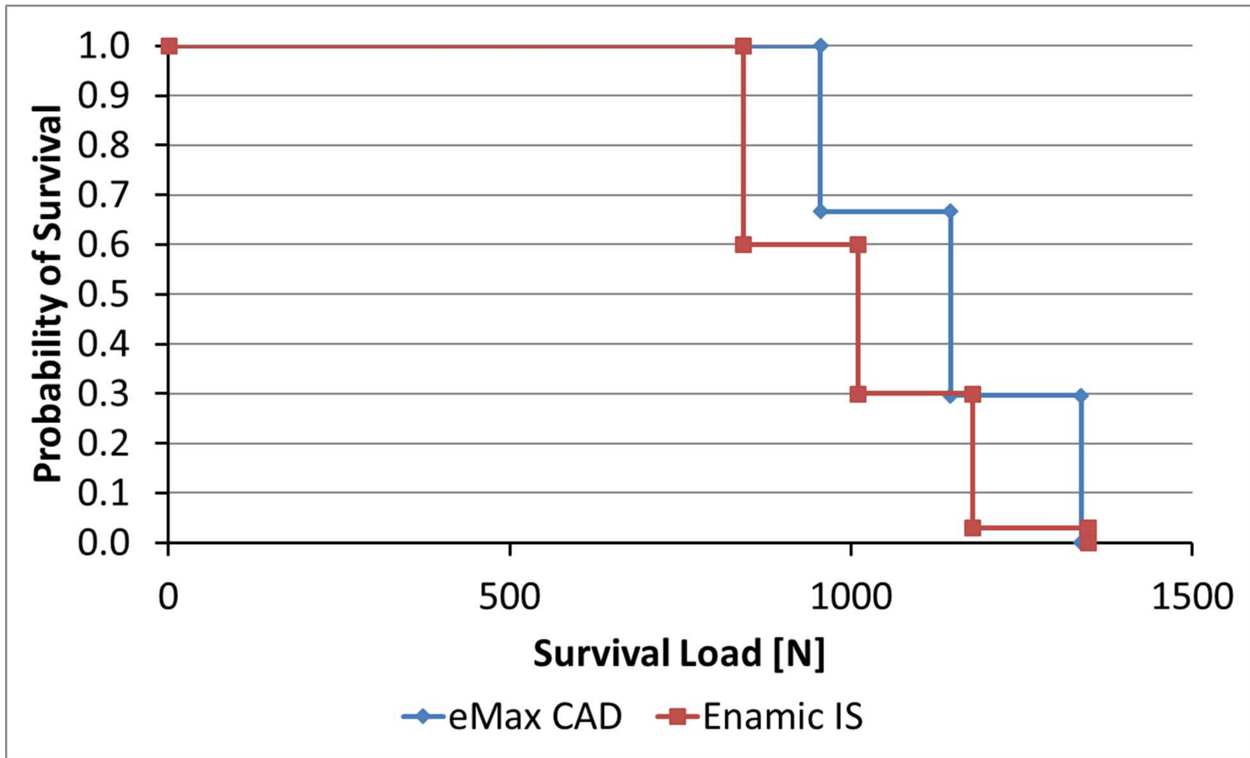

Figure 10 Probability of survival of eMax vs Enamic

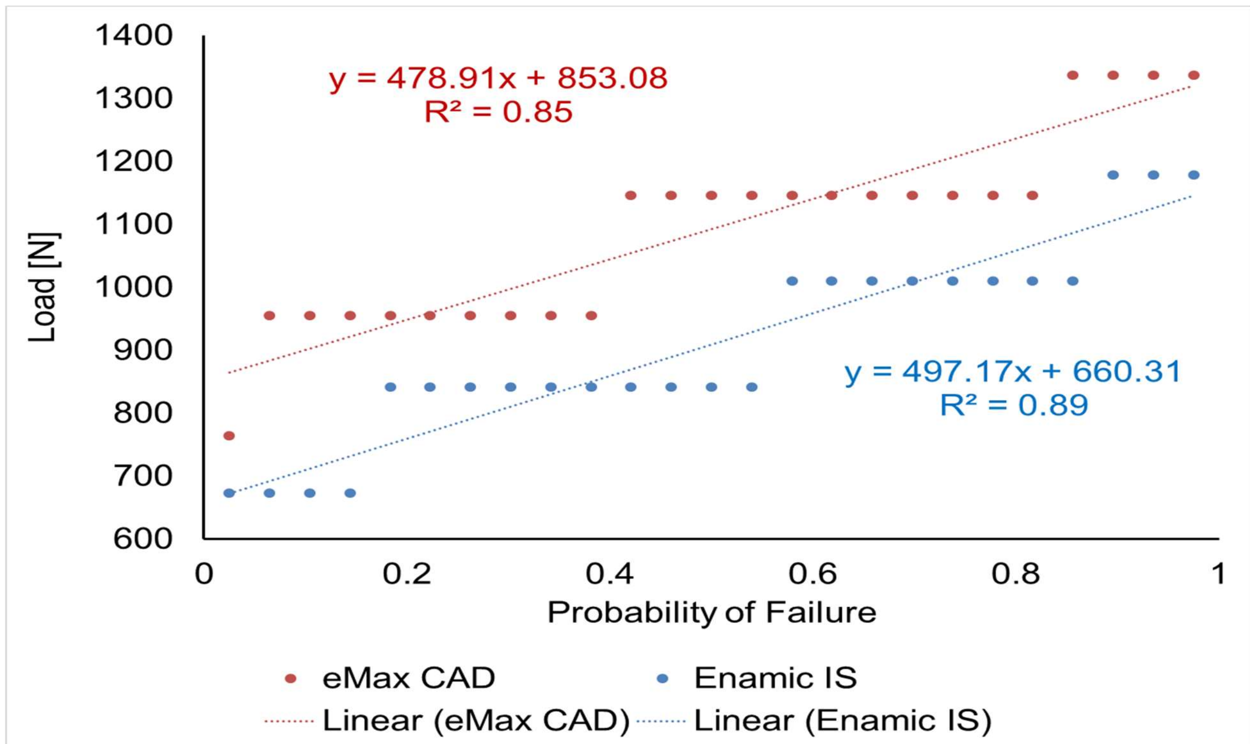

Figure 11 Probability of Failure of eMax vs Enamic. The dots in the same line represent the SD.

Figure 10 describes the probability of survival, which is irrespective of the number of cycles. The eMax group exhibited a greater strength than Enamic. Figure 11 describes the probability of failure in relation to the load of both groups. As load approaches to higher failure, it appears to have a linear relationship. At a lower load, there is a lower probability of failure.

Discussion

Unlike Hoffman's study, there were no screw separations or failures of the acrylic base. This is likely due to the on axis load that was applied and validates that dental implants best sustains forces directed along their long axis[12]. Debonding of the crown from the TiBase was a mode of failure identified with the Zirconia group. However, fracture of the ceramic with the TiBase intact was the only mode of failure included in this analysis. In comparison to a hybrid crown which has two components, a hybrid abutment has three: a ceramic crown, a ceramic abutment and a TiBase. The crown may be cement retained or screwmentable as described above. Cementation of a ceramic crown onto a mesostructure may introduce an additional point of failure not produced in a hybrid crown. The clinician furthermore has countless options in material selection for the mesostructure and crown. Though the same material may be used, different ceramics may be considered, such as a Zirconia hybrid abutment with a Lithium Disilicate crown. Implant restorations using the hybrid abutment concept should be further investigated.

Although the static load to failure was not statistically significant, there was a greater statistical difference in endurance limit between eMax and Enamic. Based on these results, either material may be a suitable choice for provisionally restoring an implant. However in considering the long term survival of a permanent restoration, eMax is superior to Enamic at enduring loads over time. Despite the improved flexural strength of Zirconia and eMax, Enamic offers a lower modulus of elasticity similar to dentin. It can be argued that the resiliency of Enamic make it a better solution for implants where the periodontal ligament is lost. The ceramic structure is infused with a polymer which distributes forces of heavy loads, acting as a shock absorber[13]. Additional studies may explore this further.

Cyclic fatigue testing can simulate how the material would perform over a lifespan of loading. The 6000 cycles that each sample underwent is equivalent to 6 months of clinical

service. However these forces do not fully replicate oral forces. The piston was not elevated off of the restoration and a constant pressure was applied to the samples in efforts to condense the study time. In comparison to normal functioning and chewing, opposing teeth may not touch for more than 10 minutes a day[14]. Further studies with increased cycles and a lower frequency would be beneficial.

The results included in this study reflect this particular case. When evaluating the crown failures, a material thickness of 2.4mm was measured which exceeds the manufacturer's recommendation. It was then identified that the implant crown was designed from a patient case, where an apical coronal ridge deformity developed following exodontia. Ideally, if the dimensions of the crown followed clinical standards of 1.5mm thickness or less, perhaps the Zirconia crowns would have fractured. Common reasons for ceramic failure are microcracks or flaws in the ceramic, as well as inadequate thickness of the ceramic restoration[13]. It is important to note that though the prefabricated TiBase abutment remains constant, the crown restoration and thickness for each patient will vary. In the absence of bone loss, factors that may restrict the interocclusal height include supracrestal placement of the implant or supraeruption of the opposing dentition. This should be taken into consideration during treatment planning.

The Sirona CAD/CAM system is widely used in Army dentistry, and was chosen for this study. The Sirona TiBase may be utilized chairside or in the laboratory and has an anti-rotational notch that is well-matched with the Sirona abutment block design. Certain limitations of the Sirona TiBase has been previously noted. Nonetheless, other TiBase systems have additional features that may better meet the unique needs of each implant restoration. Neoss TiBase abutments provide two sizes, N (narrow) and W (wide), to create different emergence profiles. The TruAbutment CEREC TiBase has a range of gingival collar heights (0.8, 1.8, 2.8 and 3.8mm) that are particularly beneficial for deeper implants. Due to the 1mm gingival height of a Sirona TiBase, bone profiling or contouring may be required for the abutment to fully seat. The extended TiBase margins of a TruAbutment may reduce this need for adjustments near the implant platform, thus enabling bone preservation. Strauman's Variobase similarly offer the flexibility of three gingival heights (1, 2 and 3mm), as well as two abutment heights (3.5 and 5.5mm). An increased benefit is its angled screw channel solution to correct implant malposition of up to 25 degrees. The Variobase design furthermore has multiple engaging mechanisms in contrast to the single antirotational element of the Sirona TiBase. This ensures a stable and

reproducible position for crown cementation to the titanium insert. Though the Sirona TiBase design facilitates an efficient and quick way to restore implants, these expanded options allow the provider to customize an implant restoration all while using prefabricated abutments. Additional studies comparing the efficacy of the various TiBase systems would be valuable.

Conclusion

All three implant supported crown materials cemented to a TiBase withstood forces greater than those observed in human dentition. Fatigue loading reduced the strength of the ceramics. Nonetheless, it can be accepted that eMax, Enamic or Zirconia may be used to restore implants in posterior dentition.

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