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FRACTURE RESISTANCE OF INCREASING CROWN HEIGHTS ON

PREFABRICATED TITANIUM ABUTMENTS

by

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DEDICATION

To Allegra and Luigi.

These past two years would not have been possible without you both.

DISCLAIMER

The views presented here are those of the author and are not to be construed as official or reflecting the views of the Uniformed Services University of the Health Sciences, the Department of Defense or the U.S. Government.

ABSTRACT

Fracture Resistance Of Increasing Crown Heights On Prefabricated Titanium Abutments

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Purpose: Prefabricated titanium base inserts (Tibases) with a monolithic crown superstructure utilizing computer aided design and computer aided milling (CAD/CAM) have become a popular technique to restore dental implants. There is little information in the dental literature or from manufacturers regarding crown-to-Tibase height ratios. The aim of the present investigation was to determine the fracture resistance of monolithic zirconia CAD/CAM implant hybrid-abutment-crowns with increasing crown heights to determine a clinically relevant crown-to-Tibase height ratio recommendation.

Material and Methods: Utilizing a 4mm Tibase height, three groups of zirconia monolithic implant hybrid abutment crown were fabricated with increasing crown heights of 6mm, 12mm, and 19.25mm to give respective crown-tibase height ratios of 1.5, 3, and 4.8. The samples were embedded in acrylic using a custom 3D printed resin holder to orient them at a 30 degrees off axis angle to the implant axis. The specimens were cyclic loaded for 250,000 cycles with a 50N force to simulate one year of chewing. Specimens were evaluated for cracking, chipping, or fractures. Reverse torque test was completed to account for screw or abutment loosening. All surviving specimens will then be subjected to a load to failure testing. The failure pattern for each specimen will be recorded.

Results: All samples survived the 250,000 cycles of cyclic loading with no evidence of cracking, chipping, or fractures. Reverse torque testing showed all specimens maintained the original insertion torque value with no evidence of screw or abutment loosening. Load to failure testing will be completed for each specimen.

Conclusions: Implant hybrid abutment crowns with crown-Tibase height ratios of up to 4.8 survived an estimated chewing simulation of one year. Load to failure testing will elucidate the biomechanical differences among the three test groups

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LIST OF ABBREVIATONS

CIR: Crown-implant ratio

CAD: Computer Aided Design

CAM: Computer Aided Manufacturing

Tibase: Prefabricated Titanium Base Insert

Ti6Al4V: Titanium-6Aluminum-4Vanadium Alloy

10-MDP: 10-Metracryloyloxydecyl Dihydrogen Phosphate

MM: Millimeter

μM: Micron

Ncm: Newton centimeter

N: Newton

C: Celsius

Min: Minute

Hz: Hertz

CHAPTER 1: Introduction

DENTAL IMPLANT CROWN-IMPLANT RATIO

Dental implants are a well-accepted and predictable treatment for the single tooth edentulous site.[1] However, unlike natural tooth abutments for traditional fixed prosthesis, there has been no agreed upon value for an acceptable crown-to-implant ratios (CIR) regarding implant survival or restoration success.[2] In a 2018 consensus statement from the European Academy for Osseointegration, Hammerle *et al*. proposed a single tooth restoration CIR between 0.9 to 2.2 to avoid both biologic and mechanical complications.[3] However, the literature is plentiful of studies and systematic reviews showing no correlation of implant or restoration failure with an increased CIR.[4-8] A retrospective cohort study completed by Urdaneta *et al*. showed no increase of crestal bone loss or implant failures with CIR of up to 4.95, though they did report a higher incidence of abutment loosening.[9] Several studies have shown an inverse relationship, reporting less peri-implant marginal bone loss around restorations with a higher CIR.[10-12] It has been reported in the literature that early crestal bone loss has been associated with clinical crown height spaces greater than 15-17mm and may be a more significant clinical factor than the CIR.[13,14] Further, with the positive outcomes and increased use of short dental implants[15] it can be concluded that clinicians may find themselves restoring more sites with increased crown height spaces and high CIR restorative situations.

PREFABRICATED TITANIUM BASE INSERTS

With the continuous advancement of computer aided design/computer aided manufacturing (CAD/CAM) the clinician and dental laboratory have numerous workflows to produce a dental implant restoration.[16,17] One pathway that has gained in popularity due to its efficient laboratory workflow and ability to be fabricated chairside is the utilization of a prefabricated titanium base insert (Tibase) (Figure 1) along with a monolithic superstructure to form an implant hybrid abutment crown (Figure 2).[18] Depending on the manufacturer, most commercially available Tibases are a titanium-6aluminum-4vanadium alloy (Ti6Al4V) featuring a stock cylinder with varying heights of 3 to 6mm on which the monolithic abutment-crown restoration is bonded. Current Tibase research has focused on the fracture resistance and/or retention of different ceramic superstructure material combinations utilizing a consistent restoration height after thermocycling and cyclic loading.[19-25] To date, there is little information in the dental literature or from manufacturers on recommended crown-to-Tibase height ratios. With increasing crown heights, the restoration will experience larger off axis forces; potentially equating to an increase of force by 20% for every 1mm of additional crown height predisposing the restoration to early biomechanical failure.[26] Failure could occur catastrophically due to a single off-axis force applied to the crown that surpasses its maximum resistance to fracture. Alternatively, during repeated mastication forces, the implant crown could fail or begin to fail due to crown-abutment cement failure, abutment screw loosening or fracture, or sub-catastrophic internal zirconia crown cracking, all contributing to reduced restoration longevity and future failure

ZIRCONIA

The use of zirconia as a definitive restoration has grown in prevalence due to its known strength and enhanced esthetics with increased yttria content.[27] Additionally, zirconia is highly polishable and is theorized to be an ideal interface with the peri-implant tissues for epithelial cell adhesion.[28] Regarding Tibase retention, zirconia can be predictably bonded with various resin cements utilizing air particle abrasion and the application of a chemical primer incorporating 10-metracryloyloxydecyl dihydrogen phosphate (10-MDP).[24]

OBJECTIVE OF STUDY

The aim of the present investigation was to determine the fracture resistance of monolithic zirconia CAD/CAM implant hybrid-abutment-crowns with increasing crown heights to determine a clinically relevant crown-to-Tibase height ratio recommendation. The null hypothesis was that increasing the crown height will not influence the fracture resistance of the implant supported hybrid-abutment-crown restorations. Secondarily, the null hypothesis was that increasing crown heights will not impact the rate of detectable cement failure, zirconia fracturing, or abutment screw loosening/fracturing.

CHAPTER 2: Materials and Methods

STUDY DESIGN

Test Groups

Twelve dental implant laboratory analogs (Lab Analog, Nobel Biocare, Kloten, Switzerland) with a 5.0mm restorative platform were utilized in this study. The analogs were embedded in a custom-made holder perpendicularly in an auto-polymerizing resin (ALIKE; GC America Inc, Alsip, IL) leaving 2mm of the analog exposed according to ISO Standard 148011[29] to simulate crestal bone resorption. Three groups of four specimens each were fabricated to restore a simulated mandibular first molar. The test groups consisted of monolithic zirconia CAD/CAM implant hybrid-abutment-crowns with identical parameters apart from increasing crown heights of 6mm, 12mm, and 19.25mm to give respective crown-to-Tibase height ratios of 1.5, 3, and 4.8 (Figure 3).

Crown Design

Mist scanbodies/scanposts were fully seated on the test group analogs embedded in the acrylic resin and scanned with a lab scanner (Freedom HD, DOF, Seoul, South Korea). Computer aided design (CAD) software (Exocad, Darmstadt, Germany) was used to ensure standardization of crown specimens and meet manufacturer's instructions for material thickness of the pre-sintered zirconia discs (IPS E.mad ZirCAD MT Multi; Ivoclar Vivadent, Schaan, Liechtenstein). Hybrid abutment crowns were designed to the anatomical parameters of a mandibular first molar with a tibase fit of 0.027". The CAD files generated were sent to a 5-axis milling machine (imes icore 350i; Articon Dental Digital Solutions, Cologne, Germany) for the monolithic zirconia crowns. The hybrid abutment crowns were fully sintered per manufacturer instructions (Programat S1 1600; Ivoclar Vivadent, Schaan, Liechtenstein). Following lab quality control inspection of accuracy of fit, the occlusal surface was polished per manufacturer instructions with no glaze applied.

Crown Superstructure

For assembling of the test groups; the screw channel of the hybrid abutment zirconia crowns was air particle abraded utilizing a circular motion with 50µm Aluminum Oxide at a pressure of 2 bar from a distance of 10mm for 10 seconds and ultrasonically cleaned for 10 minutes. The air abraded surfaces were treated with a chemical universal primer containing the molecule 10-MDP (Monobond plus/ Ivoclar Vivadent) for 60 seconds and air thinned. Tibases (MIST L-Link; Imagine USA, Chantilly, VA) with a geometry of 4.0-mm in height was utilized. Per manufacturer instructions, the Tibases were treated with a chemical primer (Monobond Plus; Ivoclar Vivadent). Utilizing an autopolymerizing adhesive resin cement (Multilink Hybrid Abutment; Ivoclar Vivadent) the two structures were bonded together under a constant seating force for 7 minutes. Excess cement was removed, and margins polished to ensure removal of the oxygen inhibited layer. All specimens were stored for 72 hours in 37°C distilled water before testing. Each restoration was torqued per manufacturer's instructions to 35-Ncm with a calibrated torque wrench. To account for screw loosening the analog-abutment complex was retorqued to 35Ncm after 10 minutes.[30] For all specimens Teflon tape was placed in the screw access channel and closed with resin composite (Filtek Supreme Ultra Universal Restorative; 3M, Saint Paul, MN) layered flush with the occlusal surface and light cured (Elipar DeepCure-S Curing Light;3M) per manufacturer instructions.

Cyclic Aging and Load to Failure

Cyclic loading was completed via a computer controlled chewing simulator (SD Mechatronics, Feldkirchen-Westerham, Germany). To provide clinically relevant data, each specimen underwent 250,000 cycles of loading at 50N with a loading frequency of 1.2-Hz to simulate 1 year of use.[31,32] Utilizing a custom 3D printed resin acrylic jig to allow consistent orientation for each specimen the loading force was applied with a 4.5-mm diameter steel ball at an angle of 30 degrees to the implant axis (Figure 4). Upon completion of loading, each specimen was evaluated at 5.5× magnification for cracking, chipping, and fractures. Any fracture, crack, or cement failure identified was described and recorded, with such specimens categorized as “failed” (Secondary Aim #1). Evidence of abutment screw loosening was determined by applying reverse torque to each specimen abutment screw. Abutment screw reverse torque values were recorded and compared to baseline (35Ncm) (Secondary Aim #2). All specimens surviving the cyclic loading will be subjected to a single load to failure test. Force will be applied at the same off axis angle of 30 degrees with a crosshead speed of 0.5mm/min. Using MTS Testworks 4 software, the loading force will be increased in 100N increments. The failure load will be recorded as the peak load recorded before the first drop in load on the generated stress/strain curve.

Statistical Analysis

Because this study is primarily designed to describe fracture resistance and relevant characteristics in dental implants with increasing crown heights, the study is not formally powered to evaluate for small to moderate differences between specimen groups. Descriptive results of this study, however, may be used to inform the design of larger experiments and their selection of relevant crown heights.

CHAPTER 3: Results

All subjects from all test groups survived 250,000 cycles of 50N cyclic loading. Upon analyzing at 5.5× magnification there was no evidence of cracking, chipping, or fractures (Table 1). All specimens were cleared to be subjected to load to failure testing. There was also no evidence of screw or abutment loosening. Reverse torque testing showed all specimens maintained the original insertion torque value per manufacturer's instructions of 35N.cm (Table 2). Load to failure testing will show the peak load at failure and a mean stress/strain curve for each specimen will be generated. The failure pattern of each specimen will also be categorized regarding the failure type.

CHAPTER 4: Discussion

The null hypothesis was partially accepted as increasing crown heights did not affect the specimens after cycling loading, however load to failure testing was not completed at this time. Long term in vivo studies[33] have shown high success rates with dental implants, therefore it is not surprising that all specimens in this study survived the one-year simulation of cyclic loading. However, in a 2012 consensus report from the European Association for Osseointegration, they reported that only 66.4% of patients were completely free from any type of complications after 5 years.[34]

Implant complications are largely classified as either biological or prosthetic in nature.[35] Examples of biologic complications are peri-implant mucositis, peri-implantitis, or implant loss. Excess luting cement retained around dental implants is a known risk factor for these peri-implant biologic complications.[36] Resin cements specifically formulated for dental implants have high retentive pull off strengths when used in conjunction with proper bonding protocols.[25] However, these resin cements have been shown to have no antimicrobial effect in the presence of subgingival gram-negative bacteria associated with peri-implant disease.[37] In fact, they produce the opposite effect; they promote bacterial adherence and significant biofilm formation.[37] Techniques have been developed to control the volume of cement used for implant restorations in hopes to decrease the amount of cement extruded into the peri-implant tissues.[38] Even with these advanced techniques retained excess cement is still a problem with restorations with subgingival margins.[39] The prefabricated Tibase with a monolithic superstructure restoration design utilized in this study allows for a cement retained and screw retrievable restoration. The monolithic superstructure is cemented extra-orally and delivered intraorally as a screw retained restoration. Screw retained restorations suffer from minimal biologic complications but are susceptible to prosthetic complications.

Prosthetic complications include screw or abutment loosening, interproximal contact loss, crown chipping or fracture, and implant fracture.[35] Screw loosening is the most prevalent complication with single tooth dental implant restorations.[35] Shillingburg *et al*. classically defined a maximum crown-root ratio of 1:1 for a tooth to be used acceptably used as an abutment.[40] However, dental implants do not behave with the same biomechanics as natural teeth as shown by the European Academy for Osseointegration's recommendation of CIR of 0.9-2.2.[3] Prefabricated Tibases introduce a new ratio of the crown-Tibase height used clinically, of which there has been little research.

Crown heights of 6mm, 12mm, and 19.25mm were used in the present study to obtain a wide range of crown-Tibase ratios of 1.5, 3, and 4.8. All crowns survived the 250,000 cyclic loading cycles. This could be attributed to the high fracture strength of the zirconia crowns and the bonding protocol used to bond the crowns to the Tibase. Zirconia was chosen for this study as it has been shown to be highly polishable leading to biocompatibility with the subgingival peri-implant tissues and low abrasiveness to the opposing dentition.[28] In terms of bond strength to the Tibase abutment, mechanical treatment such as air particle abrasion leads to higher retentive bond strengths.[25,41] However, for certain Tibase abutments, air particle abrasion showed a significant decrease in bond strengths[42], thus the clinician must defer to the manufacturer's instructions.

To prevent the frequent complication of screw loosening the dental implants underwent a second torquing of the analog-abutment complex to the manufacturer's instructions after ten minutes of waiting.[30] Larger crown heights for single unit implant restorations when loaded in eccentric forces could exhibit destructive cantilever forces which have been shown to increase prosthetic complications.[43] In this study, no restorations showed any signs of abutment loosening following cyclic loading. This is in accordance with Yilmaz *et al*[44]. who utilized increasing crown heights to investigate the stability of abutment screw joint and found no statistical difference in the de-torquing values following cyclic loading. In their study, they cyclic loaded for 5 million cycles and utilized a cyclic loading force of 120N, both significantly larger than the values utilized in the current study. They did not, however, report the height of the Tibase used, so direct comparison cannot be made with the present study, though they concluded that clinicians should not exceed crown heights of 14mm in patients with normal mastication forces.

Load to failure testing of the crown heights in the current study will elucidate any biomechanical differences in the crown heights tested. Given that higher crown heights will be exposed to larger off axis forces it can be predicted that the specimens with a crown height of 19.25mm will catastrophically fail at significantly lower forces compared to the smallest crown height of 6mm. This would be in accordance with Yilmaz *et al*[44]. not recommending crown heights exceeding 14mm. However, the mechanism of failure cannot be predicted at this time.

There are significant limitations in this study. There was a limited sample size in all groups which prohibited statistical analysis. Though cyclic loading was completed there was no thermocycling which could alter the bond of the zirconia-Tibase interface affecting failure rates. Laboratory dental analogs were used in place of endosteal dental implants. It is unclear how dental analogs replicate the restoration abutment complex in terms of maintaining the torque prescribed at delivery.

CHAPTER 5: Conclusions

Within the limitations of this study, it can be concluded that implant hybrid abutment crowns with crown to Tibase height ratios of up to 4.8 survived an estimated chewing simulation of one year. Load to failure testing will elucidate the biomechanical differences among the three test groups. Additional *in-vitro* studies with larger sample sizes and longer durations of cyclic loading are needed to support clinical recommendations.

Table 1: Cyclic Loading Results. Survival results following 250,000 cycles of 50N cyclic loading.

Test Group	N	Survived specimens
6 mm	4	4
12 mm	4	4
19.25 mm	4	4

Table 2: Revers Torque Results. Reverse torque values of test groups following cyclic loading.

Test Group	N	Reverse torque value (Ncm)
6 mm	4	35
12 mm	4	35
19.25 mm	4	35

Figure 1. Prefabricated titanium base inserts (Tibases). Examples of Tibases from different manufacturers. (1)MIST S-link external hex Tibase (2) MIST S-link internal hex Tibase (3) NT Trading internal hex Tibase (4) Dentsply Sirona internal hex Tibase (5) MIST L-link internal hex Tibase.

Figure 2. Implant Hybrid Abutment Crown. Components of monolithic implant hybrid abutment crowns. From left to right: Prefabricated titanium base insert, pre-crystalized monolithic lithium disilicate block from which the dental restoration is milled, milled and crystalized monolithic lithium disilicate implant restoration, final hybrid abutment crown that has been cemented extra-orally on the Tibase, gold coated implant delivery screw.

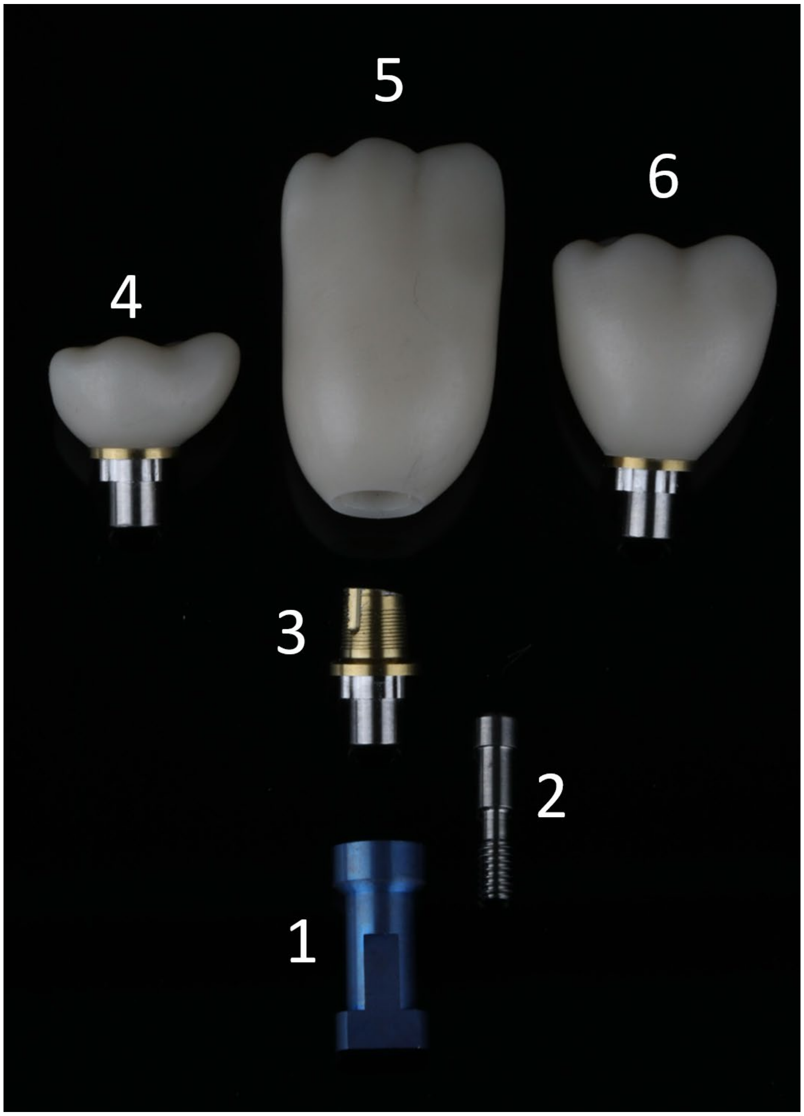

Figure 3. Test Group Components. Assembly of hybrid abutment crown test groups. (1) Laboratory implant analog. (2) Titanium screw (3) Tibase (MIST L-Link; Imagine USA, Chantilly, VA) cut to 4mm in height. (4) Completed 6mm zirconia crown cemented to the Tibsae. (5) Milled 19.25mm zirconia crown prior to cementation to the Tibase. (6) Completed 12mm zirconia crown cemented to the Tibase.

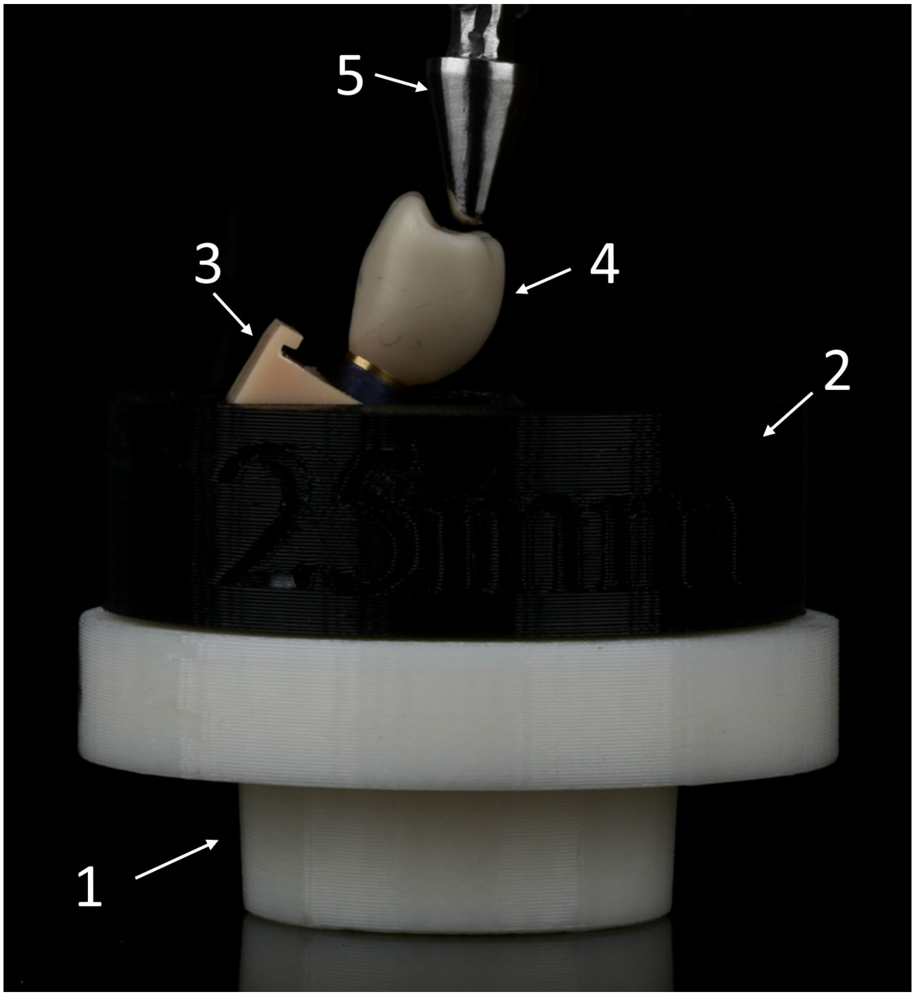

Figure 4. Cyclic Loading Setup. Experimental setup of cyclic loading 12mm test group at 30 degrees off axis to the long axis of the implant restoration. (1) Custom 3D printed mount for chewing simulator. (2) Custom 3D printed jig to allow for consistent 30 degree off axis mounting of all samples. (3) Custom 3D printed box utilized for mounting the implant analog-implant crown complex in acrylic. (4) 12mm sample specimen torqued to implant analog embedded in acrylic. (5) 4.5mm chewing simulator antagonist.

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