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FAILURE MODES OF DIFFERENT ZIRCONIA CROWN HEIGHTS AND MATERIALS ON TITANIUM BASE ABUTMENTS

by

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A THESIS

Submitted to the graduate faculty of The University of Alabama at Birmingham,
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Master of Science

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2023

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DENTISTRY

ABSTRACT

Statement of the Problem: The existing scientific literature lacks comprehensive information regarding the influence of zirconia crown height on debonding and fracture occurrences between zirconia crowns and titanium base abutments. Additionally, there is a lack of comparative studies evaluating different zirconia materials as restorative options for screw-retained restorations.

Purpose: The purpose of this study was to assess the failure modes of the zirconia crown/titanium implant abutment complex by investigating the impact of increasing zirconia crown heights and different zirconia materials.

Materials and Methods: The experimental design encompassed six groups, each consisting of 10 specimens. Group 1 included 10 non-anatomical crowns (copings) made of 8mm-tall 3Y-Zirconia, Group 2 included 10 non-anatomical crowns made of 10mm-tall 3Y-Zirconia. Group 3 included 10 non-anatomical crowns made of 12mm-tall 3Y-Zirconia, Group 4 included 10 non-anatomical crowns made of 8mm-tall 5Y-Zirconia. Group 5 included 10 non-anatomical crowns made of 10mm-tall 5Y-Zirconia, and Group 6 included 10 non-anatomical crowns made of 12mm-tall 5Y-Zirconia. All non-anatomical crowns were bonded to 4mm-tall Titanium-Base Abutments using Panavia V5 Cement. The specimens underwent load cycling with an Alabama wear tester, for 100,000 cycles. Subsequently, the specimens were loaded with a steel indenter until failure. The failure mode was visually evaluated.

Results: The results demonstrated a significant association between increasing zirconia crown heights and an elevated risk of debonding and fracture from the titanium bases. Furthermore, the findings revealed statistically significant differences in failure rates between zirconia materials.

Conclusion: The study's findings highlight that taller zirconia crowns exert increased leverage forces, leading to elevated stress concentrations. Consequently, this predisposes the restoration to mechanical failures such as debonding and fractures. Therefore, meticulous consideration should be given to the selection of crown height and material for cementation on titanium bases to minimize the risk of failure.

Keywords: zirconia, titanium base, abutment, crown height

DEDICATION

I dedicate this piece of work to my parents Giorgos and Eirini and to my brother Nikiforos. Your love is the sun that allows my soul to flourish. To my partner Nasos, who has stood by me day and night with unconditional love and support. To my friend Katerina, who travelled across the Atlantic to visit me.

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INTRODUCTION

The rehabilitation of partially and completely edentulous patients with titanium implants is a well-documented, predictable, and safe dental approach.[1] The effectiveness of an implant therapy, however, is dependent not only on the implant's osseointegration, but also on the prosthetic suprastructure, i.e., the implant-abutment-crown complex.[2,3]

There are two different methods of retaining a fixed implant restoration: screw retention and cementation. Determining the retention type, such as screw- or cement-retention, is an important step in the fabrication of the definitive restoration.[4]

Studies have shown that both types of reconstruction influence the clinical outcomes in different ways, neither fixation method is clearly advantageous over the other.[5] Cemented reconstructions exhibit more serious biological complications (implant loss, bone loss >2 mm), but screw-retained, reconstructions exhibit more technical problems. (e.g. screw loosening)

However, screw-retained reconstructions are more easily retrievable than cemented reconstructions and, therefore, technical, and eventually biological complications can be treated more efficiently. For this reason and for their apparently higher biological compatibility, these reconstructions seem to be preferable.

For both options, a crucial component of the fixed implant restoration is the abutment, which is the intermediate structure between the implant and the crown. Abutments allow the retention of the restoration and provide support.

In recent days, various materials are available regarding abutments: titanium, chrome-cobalt (Cr-Co), zirconia, and gold. Titanium and Cr-Co abutments have high resistance, however, they can cause a grey shadow in the mucosa surrounding the implant, which can affect aesthetics of final restoration; for this reason, zirconia abutments were developed, which offer a better color match to natural teeth because they have better light transmission[6,7], however, zirconia abutments very often wear or fracture at the implant platform.[8-11]

The breakthrough of titanium bases as abutments, happened mainly because these components were compatible with CAD/CAM technology, so they allow faster working times and acceptable adaptation.[12]

One of the main advantages of titanium bases is that the clinician can recover the abutment and the crown, and it can be cemented extra orally allowing the removal of any excess cement, thus avoiding possible tissue inflammation produced by the cement, and after this, it can be fixed with the screw intra-orally.[13] Another major advantage of the titanium base-crown hybrid complex is that the complete manufacturing process of the individual CAD/CAM prosthesis can be performed at the laboratory or the dental office and does not require the services of a milling center.

One of the critical components of a titanium-base concept is the need for reliable and predictable cementation between the titanium base and the crown. Among some studies, in which they evaluate the effect of different surface treatments, the research by Kemarly et al[14] seems to be very explanatory. They evaluated 90 titanium bases which were divided into three groups of thirty each. Thirty of the titanium bases received no surface treatment. Thirty were sandblasted with 50 um aluminum oxide particles at 2.0 bar pressure and the remaining 30 titanium bases were treated with tribochemical treatment at 2.0 bar pressure for 15 seconds. In each of the three groups of 30 titanium bases, 10 were conditioned with a universal primer on the bonding surface for 60 seconds and dried, 10 were treated with a treatment agent to condition the metal for 60 seconds and the remaining 10 received no chemical treatment. There was no statistically significant effect for any of the three chemical treatments. Regarding mechanical treatments, sandblasting with aluminum oxide particles was statistically significant in terms of the required pull-off strength. However, a parameter to take into account when selecting the surface treatment to be performed on the titanium base is the topography it presents, according to Arce et al[13]; they evaluated 60 titanium bases that had 15 150-micron deep grooves on the surface, which were subjected to different surface treatments: adhesive containing the 10-MDP molecule, 15 titanium bases were sandblasted with 50-micron aluminum oxide particles for 20 seconds, 15 titanium bases were sandblasted with 50-micronaluminum oxide particles for 20 seconds, and an adhesive containing the 10-MDP molecule was applied to the zirconia crowns and 15 titanium bases did not receive any surface treatment. Sandblasting with 50-micron aluminum oxide particles is contraindicated in this type of titanium bases since they seal the microgrooves affecting the topography and decreasing the adhesion force. In the same study, in terms of surface treatment, that with an adhesive that contains the 10-MDP molecule, demonstrated the highest values of adhesion. Similarly, in another study by Linkevicius et al[15], they evaluated another type of topography of the titanium bases, which presented a Laser Lock surface treatment, comparing the retention force of two cementation protocols, one in which the titanium bases were sandblasted with oxide particles 50-micron aluminum and another where no surface treatment was made; reporting that the alumina particles that remain on the surface of the titanium bases weaken the bond strength between the titanium and the ceramic, recommending the cementation of this type of titanium bases without any treatment prior to cementation. Another important factor that affects the abutment-crown bond is the type of the cement; the investigations of Wiedenmann et al[16] and Gehrke et al[17], evaluated the behavior of zirconia abutments cemented to titanium bases with different bonding agents: Multilink Hybrid Abutment- Monobond Plus (Ivoclar Vivadent), Panavia F2.0 and V5- Clearfil Ceramic Primer Plus (Kuraray) and SmartCem2 (Dentsply); which reported the highest values of adhesion in the Multilink Hybrid Abutment-Monobond Plus bonding agent.

Another critical factor that plays a significant role in the stability of the crown-titanium base complex is the height of the titanium-base abutment. Abbo et al, 2008[18] and Bergamo et al, 2020[6] found that taller abutment heights provided higher retention values in a pull-out test between zirconia crowns and titanium bases and concluded that the 4 mm height is more retentive than the 2.5 mm height of the titanium base. However, Silva et al[19] concluded that titanium base abutment heights do not influence zirconia superstructures' retentiveness as long as adhesive resin-based cements are used. These kinds of cements significantly evidenced higher retention and were the critical factor for prevention of debonding even when different titanium base heights were used. Therefore, resin cement is the preferred luting agent to cement the two components together.

Furthermore, the interface between the titanium base and the zirconia superstructure has become a concern mainly because the edge margin of the zirconia crown is in the subgingival portion of the implant. Thus, the adhesion between the abutment and the titanium base component is very important since if a separation is made in this area, it can generate peri-implant diseases; Mieda et al[20], conducted a study using a chewing simulator to compare three types of zirconia margins on a titanium base: posterior taper, shoulder, and chamfer to determine the best margin shape for safe clinical application. Among their results they found that the zirconia margin with a posterior conical shape transferred the tension to the interior of the implant, on the contrary, the chamfer margin releases stress outside the implant; the shoulder and posterior conical groups did not present fractures in the margin of the zirconia coping. Only the chamfer groups had some small fissures, in terms of de-cementation and only the shoulder margin group had marked separation on both sides. Accordingly, the authors reported that the posterior taper margin prevents deformation and damage, generating greater long-term stability with high longevity for adhesive performance between the zirconia crown and the titanium bases.

Another major factor that should be held in mind when restoring implants is that alveolar bone dimensional change due to bone resorption can lead to an unfavorable crown height space (CHS).[21] Increased intra-alveolar distance (increased CHS) due to excessive bone loss may necessitate a modified implant treatment plan, such as bone augmentation and/or the use of longer crowns. Several surgical procedures for bone augmentation have been suggested so that implants can be placed.[22] Vertical bone gain can be achieved by positioning and fixation of bone block grafts.[23] Carini and colleagues found that the use of autologous bone is associated with bone gain (average of vertical bone earned was 8.2 mm), which is higher in comparison to other augmentation techniques.[24] Moreover, the survival rate of implants placed in bone block grafts is comparable to the survival rate of implants placed in native bone.[25] Infection, soft tissue defects, and graft exposure due to soft tissue dehiscence are however frequently reported complications associated with bone block grafts.[26] In addition, longer treatment durations, an increase in patient morbidity, and a greater financial burden may discourage some patients from enduring prosthetic rehabilitation with oral implants when bone graft procedures are involved.[27] Although these techniques have gained a certain degree of success through the years, there is insufficient data on their predictability.[23,28,29] An alternative to bone augmentation techniques could be the use of short implants.[30,31] Short implants provide surgical advantages, including reduced morbidity, reduced treatment time, and reduced costs by avoiding the aforementioned surgical interventions.[30] In addition to bone quantity, bone quality, implant surface, and occlusion pattern, other factors are considered to play major roles in the survival of short implants.[32] This includes the aspect of the crown-to-implant ratio, as well as the CHS.[33] The placement of short implants would imply the presence of increased CHS, as well as increased crown-to-implant ratios. Several laboratory studies suggest that looking at crown height space and the use of long crowns is more important than focusing on the crown-to-implant ratio when assessing biomechanical effects related to prosthetic complications.[17,34-36] Complications are thought to be caused by the lever arm influence of the crown and the increased stress transmission to the implant head and the adjacent bone associated with an increased crown height.[17,34-36] According to Misch, the CHS is measured from the crest of the bone to the plane of the opposing occlusion in the posterior region and to the opposing incisal edge in the anterior region.[21] The authors reported that a CHS above 8 mm is considered to be acceptable for fixed implant restorations for hosting the restored crown and its abutment.[21] Regarding this 8 mm specification, a minimum of 2 mm above the bone for the emergence profile is required, as well as a minimum height of 4 mm for the abutment for successful crown retention, and a minimum of 2 mm is required for the occlusal veneering material. A study by Nissan et al. found that when the crown height exceeds 15 mm, technical complications such as abutment screw fracture and crown dislodgement can occur, making it a challenge for clinicians to achieve clinically acceptable results in cases of severe bone resorption.[37] Increasing the crown height may increase the risk of mechanical complications associated with implant-supported restorations, such as non-axial occlusal forces. Even increasing implant length does not offset these forces, as they are concentrated on the implant-abutment complex and the implant shoulder, leading to internal tensile and compressive stresses at the implant-abutment connection and crestal bone interfaces.[37]

While most literature focuses on the biological complications of increased crown height, such as short implants and long crowns, there is little data on the potential influence of increased crown height on technical complications, including implant or abutment fracture or instability of the implant-abutment connection.[17,34-36] The implant-abutment connection design plays a crucial role in the success of implant therapy, as it must counteract the maximum and permanent masticatory forces. Therefore, laboratory studies evaluating the effect of crown height on the long-term stability of different implant-abutment connection designs are necessary.[38]

The following (Figure 1) are examples of zirconia crowns that got debonded from the titanium bases after 1,5 years of clinical use and a zirconia crown that got fractured and debonded from the titanium base after 2 years of clinical use. We notice that the crown height is significantly taller than the titanium base height.

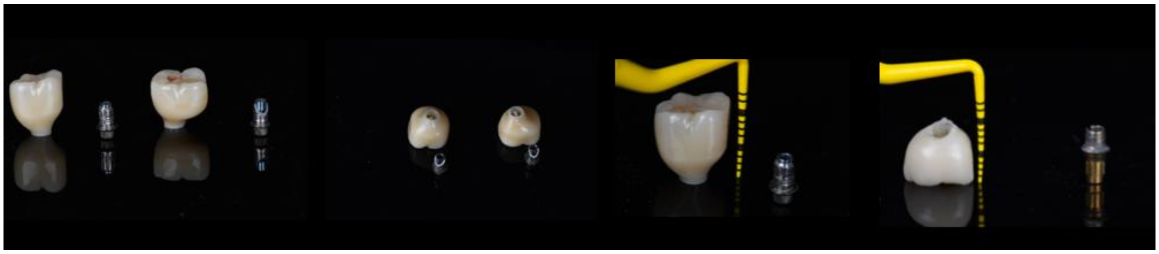

Figure 1. Clinical failure of scerw retained restoration.

As far as the actual zirconia material to be selected for the superstructure is concerned various types of zirconia are widely used for the fabrication of dental implant superstructures and fixtures. Higher yttria content zirconia has higher translucency and lower mechanical strength. The fracture strength of superstructures strongly depends on the strength on the occlusal contact region. Therefore, adequate zirconia should be selected as the superstructure crown, depending on whether strength or esthetics is prioritized.[39]

Purpose of Study

The purpose of this study was to compare the failure modes of the zirconia crown/titanium implant abutment complex with increasing zirconia crown heights and different zirconia materials (3 mol% yttria-stabilized zirconia and translucent 5 mol% yttria-stabilized zirconia).

Null Hypothesis

1) The height of the zirconia crowns cemented on the titanium base abutments will have no effect on the load to failure of the restorations.

2) The use of different zirconia materials (3Y or 5Y zirconia) will have no effect on the load to failure of the restorations.

Clinical Problem

Although numerous studies have examined the effect of titanium-base height and surface characteristics, surface treatment, and cement selection on the retention strength of titanium-base to zirconia crowns, the current literature lacks information regarding the effect of the height of the actual zirconia crowns that are cemented on top of the titanium base and its effect on debonding and fracture from the titanium base.

Many clinicians have witnessed long crowns getting debonded or fractured from the titanium bases after restorations are in use for a period of time but no consensus has been reached in the literature. Yilmaz et al. report in their 2021 recent study the effect of crown height on the titanium base zirconia crown system integrity has not been studied extensively.[11]

Currently, there are no current guidelines for the recommended height of the zirconia crown to prevent dislodgement or fracture from the titanium base. The purpose of this study is to answer questions about the suggested ratio of the zirconia crown/ titanium base systems and to help clinicians reach an evidence-based decision when planning for such a type of restoration.

In addition, 2 different zirconia material types are going to be examined, to investigate if the actual zirconia material has an effect in the survival of the titanium base-crown complex.

Objectives

- To examine the relationship between crown height and zirconia material on the load to failure of zirconia crowns bonded on titanium abutments.
- To assess the impact of different crown heights (8mm, 10mm, and 12mm) and zirconia materials (3Y and 5Y) on the mechanical performance of implant crowns.
- To identify any significant differences in failure forces among the various crown heights and zirconia materials.
- To determine the specific failure modes observed in the zirconia crown/titanium implant abutment complex.
- To provide insights and recommendations for clinicians in selecting optimal crown heights and zirconia materials for screw-retained restorations to enhance their long-term success.

MATERIALS AND METHODS

Materials Used

To investigate the effect of increasing zirconia non-anatomical crown heights and different zirconia crown materials cemented on titanium implant abutment bases, a study designed to complete a push-out test of the cemented components was defined. The materials used in the study are mentioned in (Table 1).

Table 1

Materials used

3Y – ZIRCONIA	Zirlux 16 +, Henry Schein
5Y - ZIRCONIA	Zirlux Anterior Multi, Henry Schein.
CEMENT	Panavia V5, Kuraray.
IMPLANT ANALOGS	PYIA Internal 3.5mm analogs, Biohorizons Inc.
TITANIUM BASES	PYHYB 3.5mm Hybrid Abutment Base, Biohorizons Inc.
ABUTMENT SCREW	PXMUAS., Biohorizons Inc.

Methodology

The research design for this study involved the fabrication of 60 custom-milled zirconia non-anatomical crowns simulating non-anatomical premolar crowns. Thirty of these non-anatomical crowns were made from 3Y zirconia material (Zirlux 16 +, Henry Schein) (Figure 2), while the remaining thirty were made from 5Y zirconia material (Zirlux Anterior Multi, Henry Schein) (Figure 3). To further investigate the influence of crown height, the non-anatomical crowns were divided into three groups, each consisting of ten non-anatomical crowns for 8mm, 10mm, and 12mm crown heights, respectively.

The following test groups were determined.

Group 1: (10) 8mm tall 3Y Zirconia non-anatomical crowns cemented on titanium bases.

Group 2: (10) 10mm tall 3Y Zirconia non-anatomical crowns cemented on titanium bases.

Group 3: (10) 12mm tall 3Y Zirconia non-anatomical crowns cemented on titanium bases.

Group 4: (10) 8mm tall 5Y Zirconia non-anatomical crowns cemented on titanium bases.

Group 5: (10) 10mm tall 5Y Zirconia non-anatomical crowns cemented on titanium bases.

Group 6: (10) 12mm tall 5Y Zirconia non-anatomical crowns cemented on titanium bases.

Figure 2. Zirlux 16$^+$, Henry Schein.

Figure 3. Zirlux Anterior Multi, Henry Schein.

The fabrication process of the zirconia non-anatomical crowns followed established protocols and utilized CAD/CAM technology. The design for the titanium base was created using computer-aided design (CAD) software (3Shape Dental Manager 2016) (Figure 4). The zirconia non-anatomical crowns were designed to fit the titanium base (3.5mm titanium Base by BioHorizons) (Figure 5), considering anatomical considerations of the tooth, with a cement space of 20 microns and a minimum wall thickness of 0.5mm at the cervical end and 1.2mm at the occlusal surface.

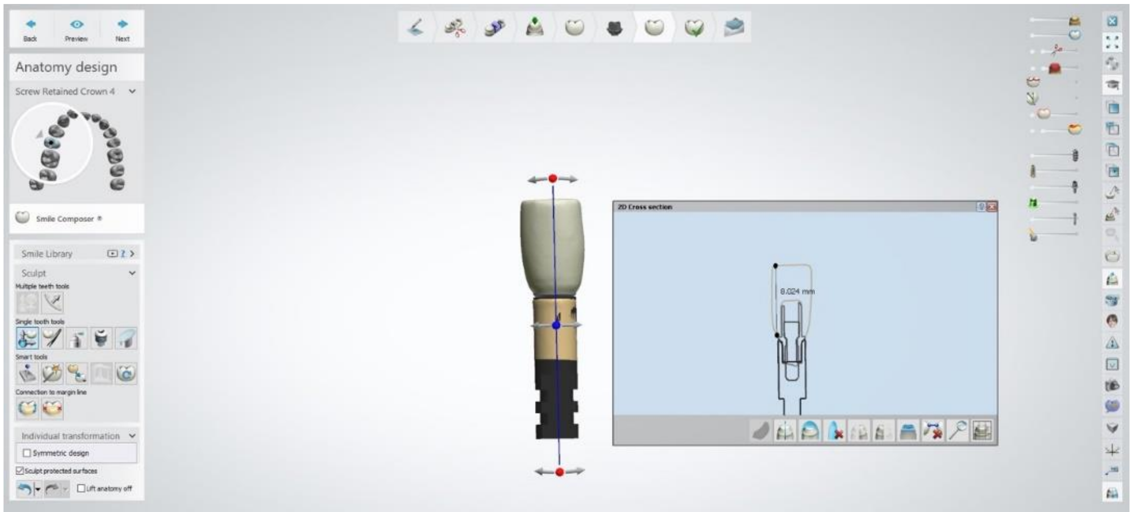

Figure 4. Designing of non-anatomical crowns (3Shape Dental Manager 2016)

Figure 5. 3.5mm titanium Base by BioHorizons

These designs were saved as .stl files and transferred to CAM software, specifically Millbox 2020 CNC Software by CIM System USA. The actual milling of the zirconia non-anatomical crowns was performed using a computer-aided milling machine, the Roland DWX-52d dry mill by Roland DGA. After the milling procedure, the non-anatomical crowns were removed from the CAM machine and underwent a final sintering process in a zirconia sintering furnace, (Sintra Plus, Shenpaz Dental LTD). After this step, the non-anatomical crowns were carefully examined for any deformation or debris and were corrected as necessary. Subsequently, the non-anatomical crowns were cleaned using a steamer machine (Steaman Cleaner Junior by Bar Instruments). (Figure 6)

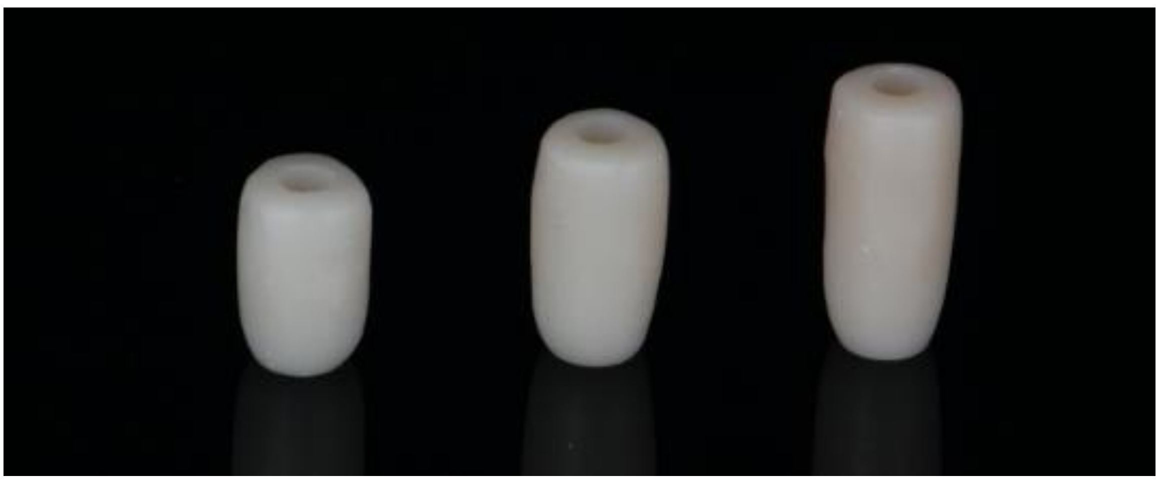

Figure 6. Non-anatomical crowns with all different heights 8mm, 10mm, 12mm after inspection.

To complete the assembly, non-anatomical crowns of each height were tried-in on commercially available titanium bases, (3.5mm titanium Base by BioHorizons). These titanium bases are cylindrical in shape and composed of Ti-6Al-4v. The bases have a facial height of 4mm and a palatal height of 2mm, as depicted in (Figure 7). The different non-anatomical crown heights represented the following titanium-base/non-anatomical crown heights ratios: 1:1, 1:1.5, and 1:2. The titanium base was securely screwed into an implant analog and torqued to 30N/cm. The access hole of the base was filled with Teflon tape, and the path of insertion of the crown was verified using orientation notches on the intaglio surface of the crown (Figure 8).

Figure 7. 3.5mm Titanium Base by BioHorizons, 4mm height.

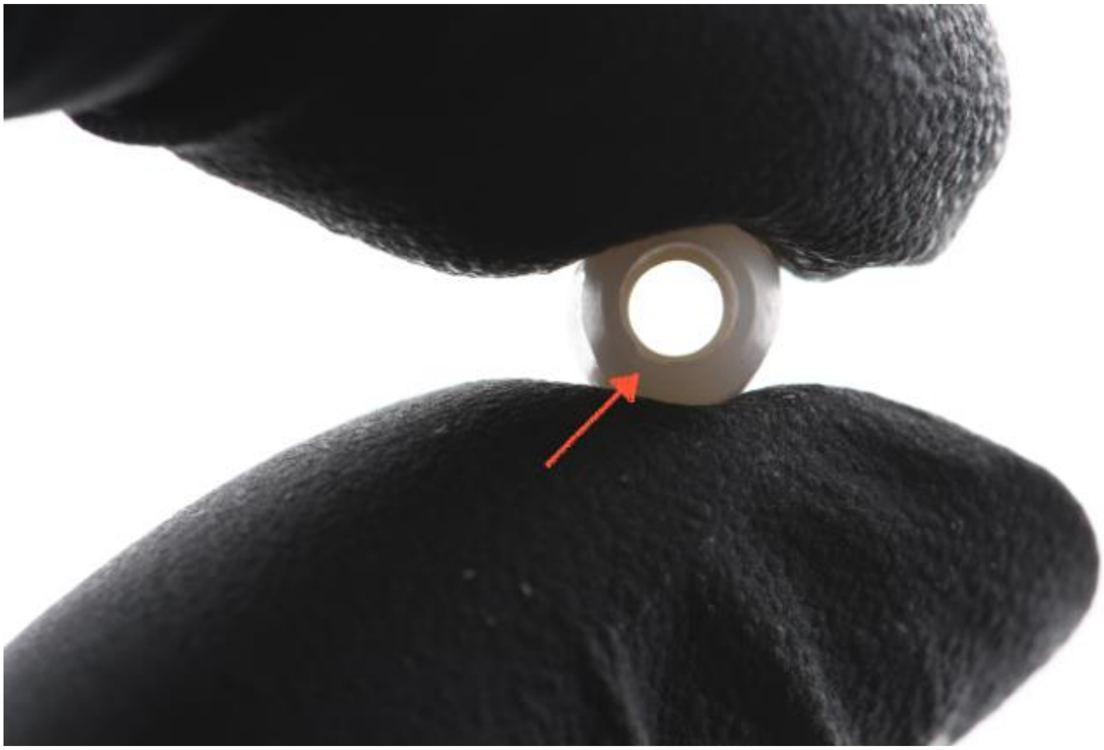

Figure 8. Orientation Notch on non-anatomical crown.

Following the evaluation of seating accuracy, the zirconia non-anatomical crowns were bonded to the titanium bases using a resin cement, (Panavia V5 by Kuraray) (Figure 9), following the manufacturer's instructions. Prior to bonding, the intaglio surface of the zirconia non-anatomical crowns underwent particle abrasion using 50µm alumina in a RENFERT Cobra sandblaster at 2 bar pressure for 20 seconds (Figure 10). Additionally, a 10-MDP-containing primer, Clearfil Ceramic Primer Plus by Kuraray, was applied to both the non-anatomical crowns and the bases after sandblasting (Figure 11-12).

Figure 9. Panavia V5 cement, Kuraray

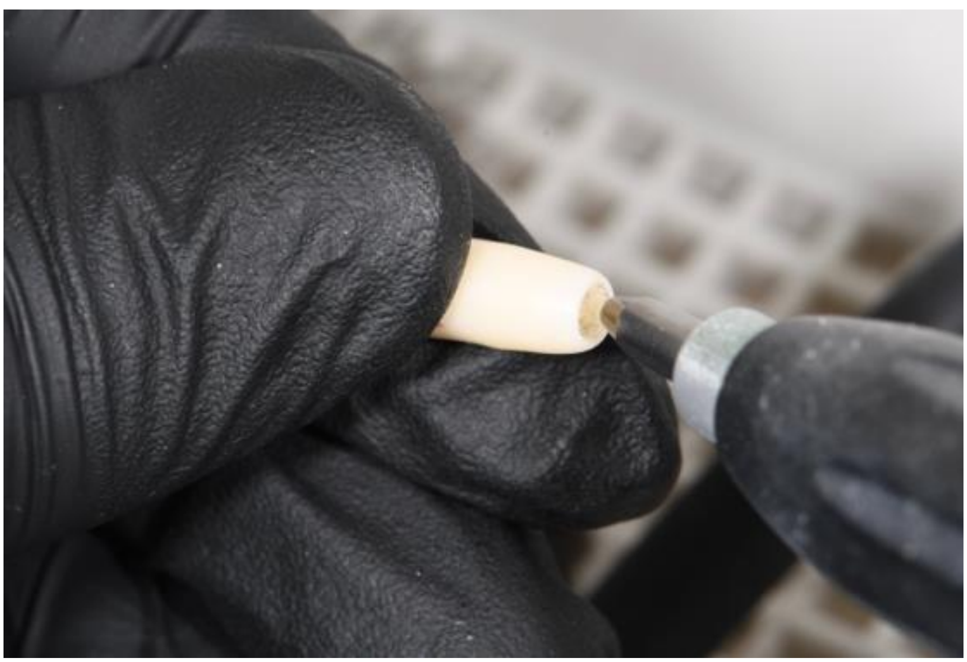

Figure 10. Sandblasting

Figure 11. Application of Clearfil Ceramic Primer Plus on titanium base.

Figure 12. Application of Clearfil Ceramic Primer Plus on non-anatomical crown.

During the seating process, all crowns were subjected to a constant force of 10N, applied using a device that ensures consistent and controlled pressure (specific device name or details are missing) (Figure 13). Excess cement was carefully removed using a micro brush (Figure 13), and the cement was light polymerized for 20 seconds on each side of the crown using a LED curing light (Bluephase G2 by Ivoclar Vivadent), with an intensity of 1200mW/cm2.

Figure 13. Showing various steps of cementation.

By following these fabrications and bonding procedures, the zirconia non-anatomical crowns were successfully prepared and securely seated on the titanium bases, ensuring standardized conditions for the subsequent load to failure testing.

Following the completion of the bonding procedures, the zirconia non-anatomical crowns, along with their respective titanium bases, were transferred and adapted to a custom-made 3D-printed mold, as shown in (Figure 14). These molds were specifically designed to securely hold the specimens during fatigue loading.

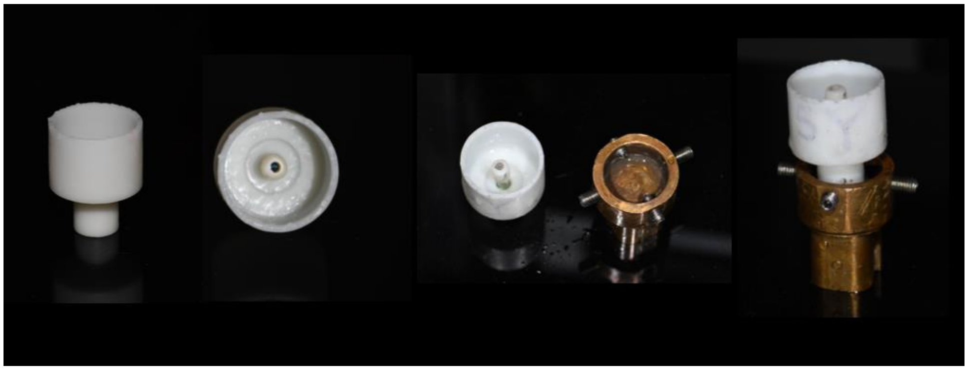

Figure 14. 3D- printed mold for securing the assembly of non-anatomical crown and analog.

The fatigue loading process was carried out using a fatigue machine, in which all specimens were placed within the molds. The specimens underwent fatigue loading for a total of 100,000 cycles at a frequency of 1.7Hz/sec, simulating one year of intra-oral use (Figure 15). This fatigue loading process aimed to evaluate the durability and performance of the non-anatomical crowns under realistic mechanical stresses and cyclic loading conditions, as depicted in (Figure 16).

Figure 15. Cycles completed.

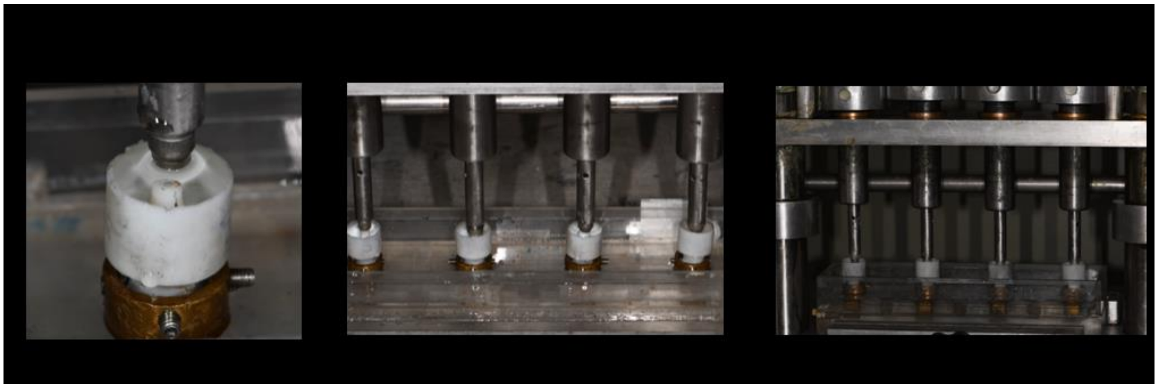

Figure 16. Cyclic loading.

After the completion of the fatigue loading phase, the specimens were transferred to a universal testing machine (Instron 5583, Instron Inc., Norwood, MA) for compressive loading tests. To perform these tests, the specimens were placed in a holding device within the testing machine, as illustrated in (Figure 17). A stainless-steel indenter with a specific diameter was utilized for applying the compressive load.

Figure 17. UTM machine with a sample loaded at 30-degree angulation.

To better simulate the mechanical forces experienced during mastication, a custom fixture was set at a 30° angle relative to the specimens, representing the orientation of a food bolus, as shown in (Figure 18). This tilting of the fixture introduced elements of tensile forces in addition to the pure compressive forces, as well as a slight sliding action, thereby creating a more realistic and complex stress distribution. This approach aimed to better replicate the clinical conditions under which crowns are subjected to various forces during function.

Figure 18. Loading protocol in UTM.

The compressive loading tests were performed at a crosshead speed of 0.5 mm/min until failure occurred. Upon failure, the load was removed, and the specimens were carefully inspected for any visual signs of failure or damage. The highest load applied prior to failure for each specimen was recorded in Newtons (N) using a computer connected to the universal testing machine (Figure 19).

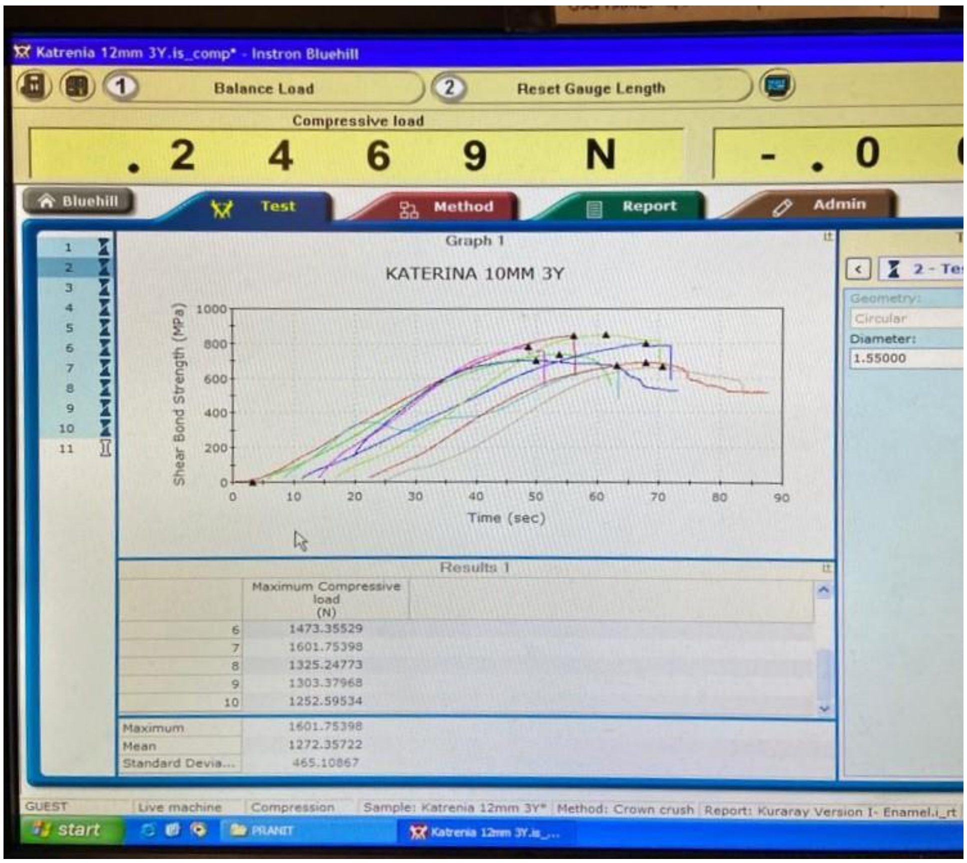

Figure 19. Computer screen showing compressive load values before fracture.

By subjecting the non-anatomical crowns to both fatigue loading and subsequent compressive loading tests, the study aimed to assess their resistance to cyclic loading and their ultimate compressive strength, providing valuable insights into their mechanical performance and potential failure modes.

RESULTS

Based on the results of the study, the null hypotheses stating that the height of zirconia crowns bonded on titanium base abutments and the use of different zirconia materials would have no effect on the load to failure of the restorations were rejected. This suggests that both the crown height and the choice of zirconia material significantly impact the load to failure of the restorations (Table 2, Figure 20).

Table 2

Failure force (N) of implant crowns raw data

	3Y			5Y		
	8mm	10mm	12mm	8mm	10mm	12mm
1	2037.39	1596.23	848.05	2278.7	1150.99	608.85
2	2136.36	1632.11	1106.31	2033.65	1083.63	683.18
3	2588.2	1388.11	1168.89	2583.35	1316.49	808.32
4	2718.59	1271.7	1149.38	1075.94	1248.75	688.49
5	2360.86	1511.07	775.39	2128.78	1203.3	745.94
6	1731.27	1473.35	1121.53	1355.33	1475.87	665.56
7	1956.85	1601.75	1083.6	2270.86	1556.44	835.19
8	3169.95	1325.24	1043.05	2140.13	1379.39	680.58
9	3244.93	1303.37	970.57	1602.19	1373.71	640.11
10	2847.46	1252.59	1095.97	1085.76	1395.27	673.11
Avg	2479.19	1435.55	1036.27	1855.47	1318.38	702.93
St Dev	519.32	145.84	131.74	535.76	147.34	71.98

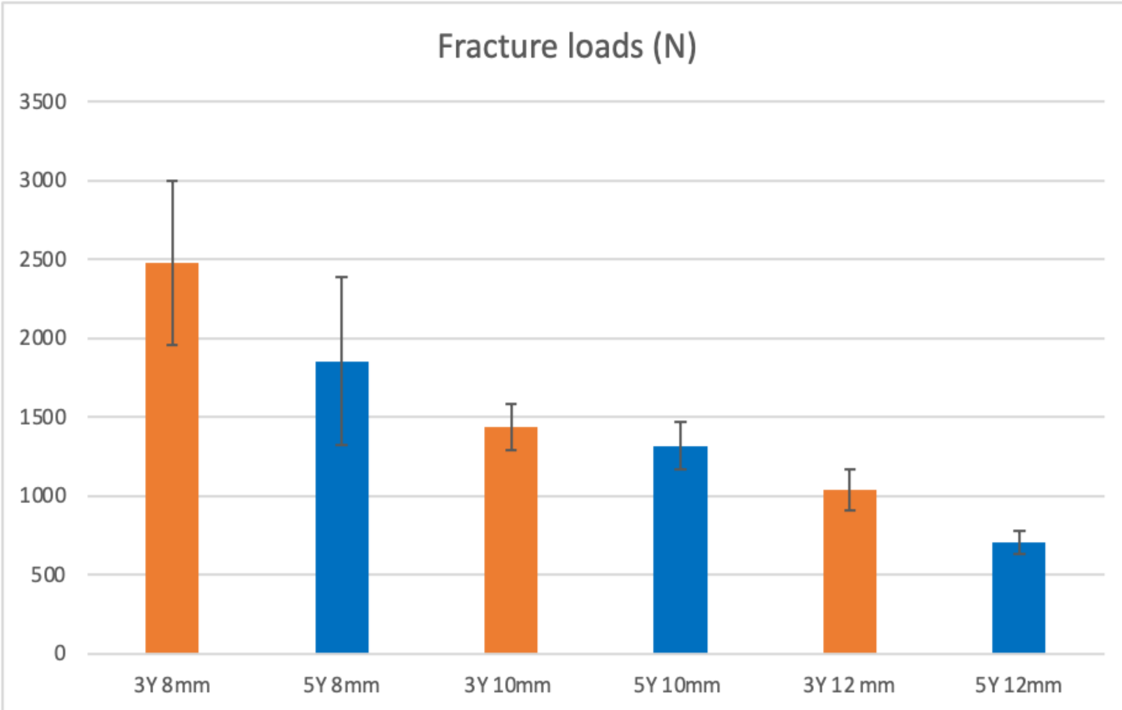

Figure 20. Mean +/- standard deviation of failure force (N) of implant crowns.

The 2-way ANOVA analysis indicated that there was a significant main effect of material ($p < .001$) and height ($p < .001$), while the interaction between material and height was not found to be significant ($p = .052$) (Figure 21).

Tests of Between-Subjects Effects

Dependent Variable: load

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	19677167.0[a]	5	3935433.399	37.947	<.001
Intercept	129883363	1	129883363	1252.381	<.001
material	1923269.165	1	1923269.165	18.545	<.001
height	17107829.7	2	8553914.851	82.480	<.001
material * height	646068.128	2	323034.064	3.115	.052
Error	5600294.524	54	103709.158		
Total	155160824	60			
Corrected Total	25277461.5	59			

a. R Squared = .778 (Adjusted R Squared = .758)

Figure 21. 2-way ANOVA analysis.

load

Tukey HSD[a,b]

height	N	Subset		
		1	2	3
12	20	869.6035		
10	20		1376.9680	
8	20			2167.3275
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.
Based on observed means.
The error term is Mean Square(Error) = 103709.158.

a. Uses Harmonic Mean Sample Size = 20.000.

b. Alpha = .05.

Figure 22. Post-hoc Tukey HSD using SPSS.

To further explore the differences in failure force among different crown heights, a Tukey post-hoc test was conducted. The post-hoc test results revealed statistically distinct groups based on crown height. Specifically, the 8mm crown height exhibited the highest failure force, followed by the 10mm crown height, and finally the 12mm crown height. These findings suggest that shorter crown heights were associated with higher failure forces than taller ones (Figure 22).

Regarding the zirconia material, as there were only two groups (3Y and 5Y), a separate post-hoc test was not required. However, it was observed that the 3Y zirconia group had a significantly higher failure force compared to the 5Y zirconia group. This indicates that the 3Y zirconia material exhibited greater resistance to failure than the 5Y zirconia material (Table 2).

Overall, the results emphasize the importance of considering both crown height and zirconia material when selecting restorative options for screw-retained restorations.

Shorter crown heights (8mm and 10mm) were associated with higher failure forces, indicating a potential risk of debonding and fractures. Additionally, the choice of zirconia material played a significant role in the failure force, with the 3Y zirconia material demonstrating better mechanical performance compared to the 5Y zirconia material.

The failure modes observed in the zirconia crown/titanium implant abutment complex varied depending on the combination of crown height and zirconia material. Among the 3Y zirconia crowns, the 8mm height group exhibited a combination of complete debond, complete debond with fracture, debond with screw deformation, and screw fracture. The 10mm height group primarily experienced complete debond, with a few instances of screw deformation. In the 12mm height group, complete debond with fracture and debond with screw deformation were the most prevalent (Figure 23).

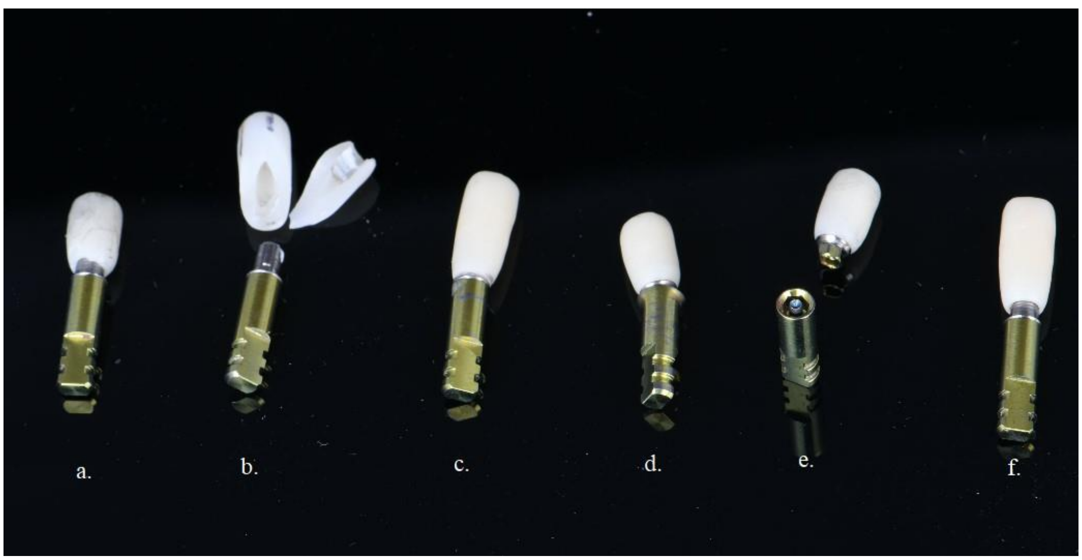

Figure 23. Showing a-complete debond with screw deformation, b- complete debond and fracture, c-screw deformation, d- screw deformation, e- screw fracture, f- complete debond.

For the 5Y zirconia crowns, all three height groups (8mm, 10mm, and 12mm) had the same frequency of cases. However, all crowns in this group displayed a combination of crown debonding and fracture (Figure 24).

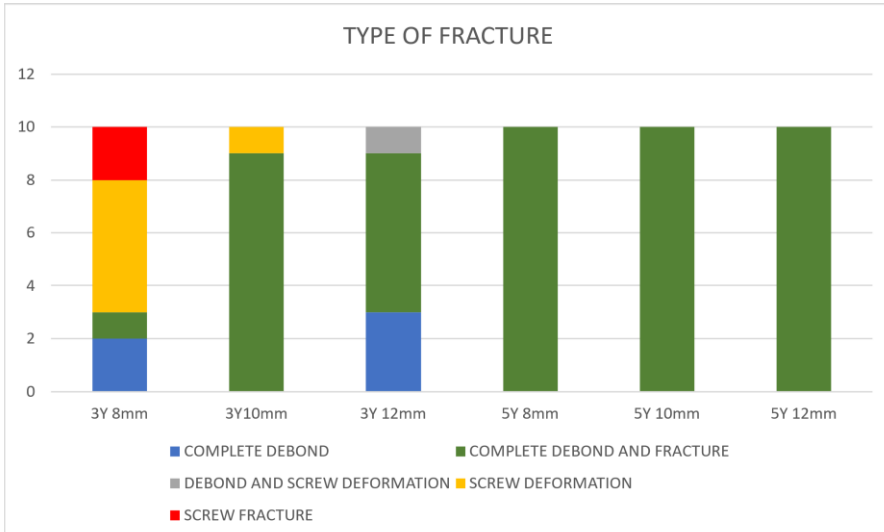

Figure 24. Type of fracture.

These findings indicate that the specific failure modes observed were influenced by both the crown height and the zirconia material used. The 8mm height group showed a higher incidence of screw deformation, suggesting that the mechanical forces exerted on these crowns may have led to the deformation of the underlying screws. On the other hand, the 10mm and 12mm height groups had a higher occurrence of complete debonding and fracture, indicating that these crown heights may be more susceptible to structural failure.

Further analysis and interpretation of the failure modes can provide valuable insights into the mechanical behavior and potential vulnerabilities of the zirconia crown/titanium implant abutment complex. This information can help guide clinicians in selecting appropriate crown heights and zirconia materials to minimize the risk of specific failure modes and improve the long-term success of implant restorations.

DISCUSSION

The results of the study provide valuable insights into the influence of crown height and zirconia material on the load to failure of implant crowns. The null hypotheses stating that these factors would have no effect on the load to failure were rejected, indicating that both crown height and zirconia material significantly impact the strength of restorations.

Firstly, the analysis revealed a significant main effect of material and height, indicating that both factors independently contribute to load failure. The interaction between material and height was not found to be significant ***($p = .052$),*** suggesting that the combined effect of these factors may not be different from their individual effects.

In terms of crown height, the post-hoc Tukey test revealed distinct groups based on crown height, with the 8mm height exhibiting the highest failure resistance, followed by the 10mm height, and finally the 12mm height. These findings suggest that taller crown heights are associated with lower failure forces, indicating a potential risk of debonding and fractures. Therefore, selecting the appropriate crown height is crucial to ensure the longevity of screw-retained restorations.

The findings of this study are in line with previous research by Gehrke et al, 2013[40], which reported similar outcomes when investigating the impact of crown height on implant restorations. The association between taller zirconia crowns and increased failure rates can be attributed to several factors.

Taller zirconia crowns introduce higher leverage forces on the underlying titanium base. This increased leverage can lead to elevated stress concentrations at the zirconia-titanium interface, making the restoration more prone to mechanical failures such as debonding, fractures or screw loosening. The findings of this study reinforce the importance of considering crown height selection as a crucial factor in minimizing the risk of failure. Also Lee et al, 2019[41] found that taller crowns can result in compromised esthetics, including excessive gingival display or a "gummy smile."

The study results indicate that the ratio between titanium bases and crown height plays a crucial role in the failure of implant restorations. It was observed that when the crown height exceeded the doubled height of the titanium base, the failure rate significantly increased. This finding emphasizes the importance of maintaining a proper proportion between the height of the crown and the underlying titanium base to ensure the stability and longevity of the restorations. Clinicians should carefully consider and adhere to the recommended ratio guidelines to minimize the risk of failure and enhance the overall success of implant-supported crowns.

The comparison between the 3Y and 5Y zirconia groups in the study revealed a significant difference in fracture resistance, with the 3Y zirconia material demonstrating superior mechanical performance compared to the 5Y zirconia material. This finding has important implications for clinicians when selecting zirconia materials for implant restorations. The higher fracture resistance observed in the 3Y zirconia group suggests that this material offers enhanced strength and durability, making it a favorable choice for long-term success. Implant restorations are subjected to significant occlusal forces and mechanical stresses, which can potentially lead to fractures and failures over time.

By opting for the 3Y zirconia material, clinicians can provide patients with restorations that are more resistant to these mechanical challenges. The improved fracture resistance of the 3Y zirconia material may contribute to a decreased risk of crown failure, debonding, or other complications, ultimately leading to enhanced longevity and patient satisfaction. It is important to note that the selection of zirconia materials should be based on a comprehensive evaluation of individual patient factors, such as occlusal considerations, esthetic demands, and clinical indications. However, the results of this study highlight the favorable mechanical properties of the 3Y zirconia material and suggest its potential as a preferred choice for implant restorations.

These results are consistent with previous literature on the mechanical properties of zirconia materials in the study done by Ban et al[39] and systematic literature review by Laumbacher[42] providing valuable insights for clinicians in selecting appropriate crown heights and zirconia materials to enhance the long-term success and durability of implant restorations.

In a similar study by Rohr et al[43] there is a strong correlation between fracture loads and fracture toughness of each ceramic crown material on implant restorations. This highlights the importance of considering the strength of the crowns on the occlusal contact region when assessing the fracture strength of superstructures. It is concluded that the selection of an appropriate zirconia material for the superstructure crown should depend on whether strength or aesthetics is prioritized and should take into account the occlusal force and repair position of the patient.

The study also investigated the failure modes observed in the zirconia crown/titanium implant abutment complex. The specific failure modes varied depending on the combination of crown height and zirconia material. Among the 3Y zirconia crowns, the 8mm height group exhibited a combination of complete debond, complete debond with fracture, debond with screw deformation, and screw fracture. The 10mm height group primarily experienced complete debond, with a few instances of screw deformation. In the 12mm height group, complete debond with fracture and debond with screw deformation were the most prevalent. For the 5Y zirconia crowns, all three height groups displayed a combination of crown debonding and fracture.

These findings indicate that both crown height and zirconia material influence the specific failure modes observed. The 8mm height group showed a higher incidence of screw deformation, suggesting that the mechanical forces exerted on these crowns may have led to screw deformation. On the other hand, the 10mm and 12mm height groups had a higher occurrence of complete debonding and fracture, indicating that these crown heights may be more susceptible to structural failure.

However, it is important to acknowledge the limitations of the study. One limitation is the use of artificial aging as it may not fully replicate the long-term clinical conditions and behavior of implant restorations. The study's findings should be interpreted with caution, considering that in vivo factors such as chewing forces, oral environment, and patient-specific factors were not directly accounted for.

Furthermore, the study only examined two zirconia materials (3Y and 5Y), and additional zirconia materials commonly used in clinical practice could have provided a more comprehensive understanding of material effects on failure forces. Future studies should consider investigating a wider range of zirconia materials to evaluate their mechanical performance and failure modes.

Additionally, the study focused on load to failure as the primary outcome measure. While load to failure provides valuable information, it would be beneficial to explore other mechanical properties, such as fatigue resistance and fracture toughness, to comprehensively assess the performance of zirconia crowns bonded on titanium base abutments.

In conclusion, the results of the study emphasize the significance of crown height and zirconia material selection in implant restorations. Taller crown heights were associated with low failure forces, highlighting the importance of careful consideration when planning restorations with excessive bone loss and large restorative spaces. The 3Y zirconia material demonstrated better mechanical performance compared to the 5Y zirconia material, suggesting its favorable suitability for screw-retained restorations. However, further research is warranted to validate these findings, explore additional zirconia materials, consider in vivo factors, and evaluate other mechanical properties to enhance our understanding of the behavior and limitations of zirconia crowns bonded on titanium base abutments.

CONCLUSIONS

- Crown height and zirconia material significantly impact the load to failure of implant crowns bonded on titanium abutments.
- Shorter crown heights (8mm and 10mm) are associated with higher failure forces, indicating a potential risk of debonding and fractures.
- The use of 3Y zirconia material exhibits greater resistance to failure compared to 5Y zirconia material.
- The specific failure modes observed vary depending on the combination of crown height and zirconia material.
- Clinicians should consider both crown height and zirconia material when selecting restorative options to minimize the risk of specific failure modes and improve the long-term success of implant restorations.
- It is important to note that further research is needed to validate these findings and explore additional factors that may influence the performance of implant crowns.

LIST OF REFERENCES

1. Busenlechner D, Fürhauser R, Haas R, Watzek G, Mailath G, Pommer B. Long-term implant success at the Academy for Oral Implantology: 8-year follow-up and risk factor analysis. *J Periodontal Implant Sci*. Jun 2014;44(3):102-8. doi:10.5051/jpis.2014.44.3.102

2. Saadoun AP, Le Gall MG, Touati B. Current trends in implantology: part II--treatment planning, aesthetic considerations, and tissue regeneration. *Pract Proced Aesthet Dent*. Nov-Dec 2004;16(10):707-14; quiz 716.

3. Tischler M. Dental implants in the esthetic zone. Considerations for form and function. *N Y State Dent J*. Mar 2004;70(3):22-6.

4. Wittneben JG, Joda T, Weber HP, Brägger U. Screw retained vs. cement retained implant-supported fixed dental prosthesis. *Periodontol 2000*. Feb 2017;73(1):141-151. doi:10.1111/prd.12168

5. Korsch M, Walther W. Retrospective analysis of loosening of cement-retained vs screw-retained fixed implant-supported reconstructions. *Quintessence Int*. Jul-Aug 2015;46(7):583-9. doi:10.3290/j.qi.a34077

6. E TPB, Zahoui A, Luri Amorin Ikejiri L, et al. Retention of zirconia crowns to Ti-base abutments: effect of luting protocol, abutment treatment and autoclave sterilization. *J Prosthodont Res*. Jun 30 2021;65(2):171-175. doi:10.2186/jpr.JPOR_2019_537

7. Shokouhinejad N, Hoseini A, Gorjestani H, Raoof M, Assadian H, Shamshiri AR. Effect of phosphate-buffered saline on push-out bond strength of a new bioceramic sealer to root canal dentin. *Dent Res J (Isfahan)*. Sep 2012;9(5):595-9. doi:10.4103/1735-3327.104879

8. Goodis HE, Marshall GW, Jr., White JM, Gee L, Hornberger B, Marshall SJ. Storage effects on dentin permeability and shear bond strengths. *Dent Mater*. Mar 1993;9(2):79-84. doi:10.1016/0109-5641(93)90079-6

9. Jung RE, Zembic A, Pjetursson BE, Zwahlen M, Thoma DS. Systematic review of the survival rate and the incidence of biological, technical, and aesthetic complications of single crowns on implants reported in longitudinal studies with a mean follow-up of 5 years. *Clin Oral Implants Res*. Oct 2012;23 Suppl 6:2-21. doi:10.1111/j.1600-0501.2012.02547.x

10. Torabinejad M, Anderson P, Bader J, et al. Outcomes of root canal treatment and restoration, implant-supported single crowns, fixed partial dentures, and extraction without replacement: a systematic review. *J Prosthet Dent*. Oct 2007;98(4):285-311. doi:10.1016/s0022-3913(07)60102-4

11. Yilmaz B, Gouveia D, Seghi RR, Johnston WM, Lang LA. Effect of crown height on the screw joint stability of zirconia screw-retained crowns. *J Prosthet Dent*. Dec 2022;128(6):1328-1334. doi:10.1016/j.prosdent.2021.02.027

12. Conejo J, Kobayashi T, Anadioti E, Blatz MB. Performance of CAD/CAM monolithic ceramic Implant-supported restorations bonded to titanium inserts: A systematic review. *Eur J Oral Implantol*. 2017;10 Suppl 1:139-146.

13. Arce C, Lawson NC, Liu PR, Lin CP, Givan DA. Retentive Force of Zirconia Implant Crowns on Titanium Bases Following Different Surface Treatments. *Int J Oral Maxillofac Implants*. May/June 2018;33(3):530–535. doi:10.11607/jomi.5915

14. Kemarly K, Arnason SC, Parke A, Lien W, Vandewalle KS. Effect of Various Surface Treatments on Ti-Base Coping Retention. *Oper Dent*. Jul 1 2020;45(4):426-434. doi:10.2341/19-155-lr

15. Linkevicius T, Caplikas A, Dumbryte I, Linkeviciene L, Svediene O. Retention of zirconia copings over smooth and airborne-particle-abraded titanium bases with different resin cements. *J Prosthet Dent*. Jun 2019;121(6):949-954. doi:10.1016/j.prosdent.2018.08.012

16. Wiedenmann F, Liebermann A, Spintzyk S, Eichberger M, Stawarczyk B. Influence of Different Cleaning Procedures on Tensile Bond Strength Between Zirconia Abutment and Titanium Base. *Int J Oral Maxillofac Implants*. Nov/Dec 2019;34(6):1318-1327. doi:10.11607/jomi.7638

17. Gehrke P, Alius J, Fischer C, Erdelt KJ, Beuer F. Retentive strength of two-piece CAD/CAM zirconia implant abutments. *Clin Implant Dent Relat Res*. Dec 2014;16(6):920-5. doi:10.1111/cid.12060

18. Abbo B, Razzoog ME, Vivas J, Sierraalta M. Resistance to dislodgement of zirconia copings cemented onto titanium abutments of different heights. *J Prosthet Dent*. Jan 2008;99(1):25-9. doi:10.1016/s0022-3913(08)60005-0

19. Silva CEP, Soares S, Machado CM, et al. Effect of CAD/CAM Abutment Height and Cement Type on the Retention of Zirconia Crowns. *Implant Dent*. Oct 2018;27(5):582-587. doi:10.1097/id.0000000000000811

20. Mieda M, Atsuta I, Matsushita Y, et al. The effective design of zirconia coping on titanium base in dental implant superstructure. *Dent Mater J*. Mar 30 2018;37(2):237-243. doi:10.4012/dmj.2017-022

21. Misch CE, Goodacre CJ, Finley JM, et al. Consensus conference panel report: crown-height space guidelines for implant dentistry-part 1. *Implant Dent*. Dec 2005;14(4):312-8. doi:10.1097/01.id.0000188375.76066.23

22. McAllister BS, Haghighat K. Bone augmentation techniques. *J Periodontol*. Mar 2007;78(3):377-96. doi:10.1902/jop.2007.060048

23. Roccuzzo M, Savoini M, Dalmasso P, Ramieri G. Long-term outcomes of implants placed after vertical alveolar ridge augmentation in partially edentulous patients: a 10-year prospective clinical study. *Clin Oral Implants Res*. Oct 2017;28(10):1204-1210. doi:10.1111/clr.12941

24. Carini F, Longoni S, Amosso E, Paleari J, Carini S, Porcaro G. Bone augmentation with TiMesh. autologous bone versus autologous bone and bone substitutes. A systematic review. *Ann Stomatol (Roma)*. Oct-Dec 2014;5(Suppl 2 to No 2):27-36.

25. Aloy-Prósper A, Peñarrocha-Oltra D, Peñarrocha-Diago M, Peñarrocha-Diago M. The outcome of intraoral onlay block bone grafts on alveolar ridge augmentations: a systematic review. *Med Oral Patol Oral Cir Bucal*. Mar 1 2015;20(2):e251-8. doi:10.4317/medoral.20194

26. Chaushu G, Mardinger O, Peleg M, Ghelfan O, Nissan J. Analysis of complications following augmentation with cancellous block allografts. *J Periodontol*. Dec 2010;81(12):1759-64. doi:10.1902/jop.2010.100235

27. Esposito M, Barausse C, Pistilli R, Sammartino G, Grandi G, Felice P. Short implants versus bone augmentation for placing longer implants in atrophic maxillae: One-year post-loading results of a pilot randomised controlled trial. *Eur J Oral Implantol*. Autumn 2015;8(3):257-68.

28. Anitua E, Alkhraisat MH. Is Alveolar Ridge Split a Risk Factor for Implant Survival? *J Oral Maxillofac Surg*. Nov 2016;74(11):2182-2191. doi:10.1016/j.joms.2016.06.182

29. Chiapasco M, Zaniboni M, Boisco M. Augmentation procedures for the rehabilitation of deficient edentulous ridges with oral implants. *Clin Oral Implants Res*. Oct 2006;17 Suppl 2:136-59. doi:10.1111/j.1600-0501.2006.01357.x

30. Jain N, Gulati M, Garg M, Pathak C. Short Implants: New Horizon in Implant Dentistry. *J Clin Diagn Res*. Sep 2016;10(9):Ze14-ze17. doi:10.7860/jcdr/2016/21838.8550

31. Pommer B, Busenlechner D, Fürhauser R, Watzek G, Mailath-Pokorny G, Haas R. Trends in techniques to avoid bone augmentation surgery: Application of short implants, narrow-diameter implants and guided surgery. *J Craniomaxillofac Surg*. Oct 2016;44(10):1630-1634. doi:10.1016/j.jcms.2016.08.012

32. Urdaneta RA, Rodriguez S, McNeil DC, Weed M, Chuang SK. The effect of increased crown-to-implant ratio on single-tooth locking-taper implants. *Int J Oral Maxillofac Implants*. Jul-Aug 2010;25(4):729-43.

33. Blanes RJ, Bernard JP, Blanes ZM, Belser UC. A 10-year prospective study of ITI dental implants placed in the posterior region. II: Influence of the crown-to-implant ratio and different prosthetic treatment modalities on crestal bone loss. *Clin Oral Implants Res*. Dec 2007;18(6):707-14. doi:10.1111/j.1600-0501.2006.01307.x

34. Bulaqi HA, Mousavi Mashhadi M, Safari H, Samandari MM, Geramipanah F. Effect of increased crown height on stress distribution in short dental implant components and their surrounding bone: A finite element analysis. *J Prosthet Dent*. Jun 2015;113(6):548-57. doi:10.1016/j.prosdent.2014.11.007
35. Nazari V, Ghodsi S, Alikhasi M, Sahebi M, Shamshiri AR. Fracture Strength of Three-Unit Implant Supported Fixed Partial Dentures with Excessive Crown Height Fabricated from Different Materials. *J Dent (Tehran)*. Nov 2016;13(6):400-406.

36. Sütpideler M, Eckert SE, Zobitz M, An KN. Finite element analysis of effect of prosthesis height, angle of force application, and implant offset on supporting bone. *Int J Oral Maxillofac Implants*. Nov-Dec 2004;19(6):819-25.
37. Nissan J, Ghelfan O, Gross O, Priel I, Gross M, Chaushu G. The effect of crown/implant ratio and crown height space on stress distribution in unsplinted implant supporting restorations. *J Oral Maxillofac Surg*. Jul 2011;69(7):1934-9. doi:10.1016/j.joms.2011.01.036

38. Ernst CP, Canbek K, Euler T, Willershausen B. In vivo validation of the historical in vitro thermocycling temperature range for dental materials testing. *Clin Oral Investig*. Sep 2004;8(3):130-8. doi:10.1007/s00784-004-0267-2

39. Ban S. Classification and Properties of Dental Zirconia as Implant Fixtures and Superstructures. *Materials (Basel)*. Aug 27 2021;14(17)doi:10.3390/ma14174879

40. Gehrke S. Importance of Crown Height Ratios in Dental Implants on the Fracture Strength of Different Connection Designs: An In Vitro Study. *Clinical implant dentistry and related research*. 10/24 2013;17doi:10.1111/cid.12165

41. Lee Y, Oh KC, Kim NH, Moon HS. Evaluation of Zirconia Surfaces after Strong-Acid Etching and Its Effects on the Shear Bond Strength of Dental Resin Cement. *Int J Dent*. 2019;2019:3564275. doi:10.1155/2019/3564275

42. Laumbacher H, Strasser T, Knüttel H, Rosentritt M. Long-term clinical performance and complications of zirconia-based tooth- and implant-supported fixed prosthodontic restorations: A summary of systematic reviews. *J Dent*. Aug 2021;111:103723. doi:10.1016/j.jdent.2021.103723

43. Rohr N, Märtin S, Fischer J. Correlations between fracture load of zirconia implant supported single crowns and mechanical properties of restorative material and cement. *Dent Mater J*. Mar 30 2018;37(2):222-228. doi:10.4012/dmj.2017-111