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Comparison of the Microgap between Titanium and Modified Zirconia Abutments after Cyclic Loading: A Pilot Study

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A Thesis Presented to the Faculty of the College of Dental Medicine of Nova
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By:

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Department of Prosthodontics
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May 2016

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I certify that I am the sole author of this thesis, and that any assistance I received in its preparation has been fully acknowledged and disclosed in the thesis. I have cited any sources from which I used ideas, data, or words, and labeled as quotations any directly quoted phrases or passages, as well as providing proper documentation and citations. The thesis was prepared by me, specifically for the M.S. degree and for this assignment.

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ABSTRACT

Comparison of the microgap between titanium and modified zirconia abutments after cyclic loading: A pilot study

Purpose: Dental implants have been a common treatment modality for the replacement of missing teeth. Dental abutment is the implant component that connects the implant fixture to the restoration. Many studies have evaluated the mechanical properties and biological behavior of titanium and zirconia abutments. Recently, a modified zirconia abutment, consisting of a titanium insert in the interface with the implant fixture, was developed. The purpose of this study is to compare the microgap between CAD/CAM titanium abutments and CAD/CAM modified zirconia abutments after cyclic loading at three different intervals.

Materials and methods: Sixteen implant fixtures (Biomet 3i, Palm Beach Gardens, Florida) were used for this study. Sixteen CAD/CAM abutments of the same configuration were fabricated and attached to the fixtures according to the manufacturer recommended torque of 25Ncm. Eight of those were made from titanium and eight were the modified zirconia abutments. The implant-abutment assemblies were embedded in polymerizing resin and mounted at 30 degree angulation in the loading machine. They were assigned to 4 groups: the control group that was not loaded, Group 1 that was loaded for 100,000 cycles, Group 2 that was loaded for 250,000 cycles and Group 3 that was loaded for 500,000 cycles. After sectioning lengthwise, the implant-abutment assemblies were examined under Scanning Electron Microscopy and the microgap between the abutment and the fixture was measured. The difference in the microgap was compared using analysis of variance (α=95%).

Results: No statistically significant difference was found in the microgap between the titanium and the modified zirconia abutments throughout the loading cycles ($p>0.05$). A statistically significant difference was found in the microgap between the zirconia part and the metal insert between control group and Group 3 ($p<0.05$). One of the abutment screws failed in the process of the cyclic loading, which led to catastrophic failure of the implant-abutment assembly.

Conclusions: 1) The modified zirconia abutment is a viable option for anterior restorations. 2) The microgap between the zirconia part and the titanium insert can be an issue of concern after cyclic loading fatigue. 3) Abutment screw loosening or fracture can jeopardize the long term survival of the prosthesis.

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Chapter 1: Introduction

1.1 Overview

Dental implants have been a common and very important treatment modality for over a decade. The need for fixed restorations has been increasing and implants have become the preferred treatment approach, showing very high success rates for replacing single or multiple teeth. Another reason for the shift toward implant dentistry is the esthetic and psychological factor arising from patients. Removable prosthodontics have been used for a long time, and they have proven to be very reliable for the clinical dentist. However, the feeling of having fixed restorations in the mouth elevates morale and self confidence in the majority of patients. One very challenging area in implant dentistry is placement of restorations in the anterior region, because of esthetic factors that determine the optimal treatment outcome. It is common knowledge that the preferred current treatment option for restoring single or multiple missing teeth in the anterior region is single implant crowns or implant supported FPD's.

1.2 History of Dental Implants

The human effort to restore or replace compromised dentition goes back centuries. In approximately 2500 BC, the ancient Egyptians tried to stabilize teeth that were periodontally involved with the use of ligature wire made of gold. The first evidence of dental implants is attributed to the Mayan population roughly around 600 AD where they utilized pieces of shells as implants, as a replacement for mandibular teeth.[1] Dr. EJ Greenfield, in 1913, placed a "24-gauge hollow latticed cylinder of iridio-platinum soldered with 24-karat gold" as an artificial root to "fit exactly the circular incision made for it in the jaw-bone of the patient”. In 1938, Dr. P.B. Adams patented a cylindrical endosseous implant that was threaded both internally and externally. It had a smooth gingival collar and a healing cap. As the progression of implant science continued, the subperiosteal (on the bone) implant was developed in the 1940’s by Dahl in Sweden.[1] The big revolution in implant dentistry occurred in late 1960’s, when the father of osseointegration, Dr P. Branemark, developed a titanium root form implant. He used four of those implants in the restoration of a severely resorbed mandible with chin and jaw deformities, which would make it challenging, if not impossible, to use a removable prosthesis. The big discovery had been made a few years earlier when he accidentally found that titanium chambers were actually bonded to the bone of rabbit femurs. [2] With his discovery, the concept of “osseointegration” came into dental science, which was defined by Dr Branemark as “direct structural and functional connection between ordered, living bone and the surface of a load carrying implant”. This concept provided the motivation for more researchers to experiment with metals utilized in orthopedic surgery in order to develop the dental implant industry. The contribution of Dr Schroder and Dr Straumann from Switzerland to the development and worldwide expansion in use of dental implants is remarkable.[3]

1.3 Dental implant restorations

Nowadays, there are numerous implant companies providing commercially available systems for clinicians. The material of selection for dental implants is commercially pure titanium. This material is the gold standard due to biological, physical and mechanical properties[4]. Some recent reports suggested that metals can induce a nonspecific autoimmunity[5], or can create galvanic side effects after contact with saliva[6]. This led to research evaluating zirconia implants as a viable option. Zirconia seems to be a suitable dental implant material because of its toothlike color, mechanical properties, and excellent biocompatibility. Further clinical research needs to be conducted before zirconia implants can be part of everyday practice.

As far as implant restorations are concerned, they can be of two main types: screw- or cement- retained. The difference is in the way that the final restoration is attached to the implant fixture. In a screw-retained restoration, the abutment and the restoration are attached together via a small screw and there is a hole in the restoration, which allows the screw to be placed using a specific torque value. Retrievability is a big advantage of these restorations, and possible complications (mainly prosthetic, like screw loosening or veneering material chipping) can be treated more easily[7]. In a cement retained restoration, there is an intermediate abutment that is screwed to the implant and the final restoration is cemented on this abutment. Those restorations offer better esthetics, but due to the presence of cement can present more biological complications (like implant loss or bone loss>2 mm)[7].

1.4 Dental abutments

1.4.1 Titanium abutments

A dental abutment is the component of the implant assembly that connects the implant fixture itself to the restoration. This can be a single or multiunit fixed or even a removable dental prosthesis. Implant abutments should have the appropriate emergence profile in order to support the surrounding soft tissue, and preferably are made from a tooth-colored material to prevent the bluish translucency of the overlying mucosa.[8] For a long time, the gold standard for anterior implant restorations has been a customized metal abutment (titanium or cast metal), which offers the clinician minimal mechanical complications, like loosening or fracture.[9]

Figure 1: Titanium abutment restoring missing central incisor.

Titanium abutments (Fig.1) are totally biocompatible and they offer satisfying wear and fracture resistance during normal masticatory function. More specifically, Bidra in his systematic review reported no fractures for titanium or cast metal abutments. The most common complication with titanium abutments in the anterior region, according to a recent study, was the abutment screw loosening and very rarely a screw fracture.[10] The screw loosening in this study could be attributed to the specific connection of the implant, which was external hex type. The abutment screw has also been identified as the weak component of titanium abutments in another study.[11] External hex implants have a history of screw loosening after long term use in the demanding oral cavity. For that reason, the most commonly used dental implants have an internal connection. Internal connection type implants have been associated with a more favorable stress distribution[12]. Merz et al demonstrated reduced tensile stresses in the interface of implant abutments upon lateral loading through the method of finite element analysis[13].

Figure 2: Implant restoration of missing central incisor.

1.4.2 Ceramic abutments

Current paradigms for treatment success in implant dentistry are based not only on the survival of the prosthesis and the mechanical properties of the restoration, but also on surrogate clinical outcomes like patient satisfaction in terms of dentogingival esthetics and health of surrounding tissues.[9] The problem that arises in metal type restorations is the opacity of the titanium abutment, which in patients with thin biotype can cause an unpleasant esthetic result, even if the finish line of the restoration is being placed subgingivally.[14,15] The inherent esthetic limitations of metal type abutments resulted in the development of ceramic type abutments for the anterior region. These abutments offer the apparent esthetic advantage of having a white or yellow shade, which matches perfectly with the restoration that is cemented on top of them. Several materials have been used for the fabrication of ceramic abutments. Alumina abutments (Al_2O_3) were initially used to overcome the esthetic concerns of clinicians but they proved to possess less favorable mechanical properties.[16,17] Butz et al, comparing the fracture load of alumina to titanium abutments under static loading, found statistically significant differences, with all but one abutments surviving the chewing simulation.[16] Tarnow confirmed the previous results, by conducting a multicenter prospective study, which showed that the handling of alumina abutments should be more sensitive, because of the low fracture resistance.[18]

1.4.3 Zirconia abutments

The need for a ceramic material with better mechanical properties compared to alumina led to the evaluation of 3-yttrium-stabilized tetragonal zirconia polycrystals-Y-TZP (commonly referred to as zirconia) as a possible implant abutment material. Considering its chemical composition, zirconia can be found in three crystalline phases; monoclinic, tetragonal and cubic.[19,20]

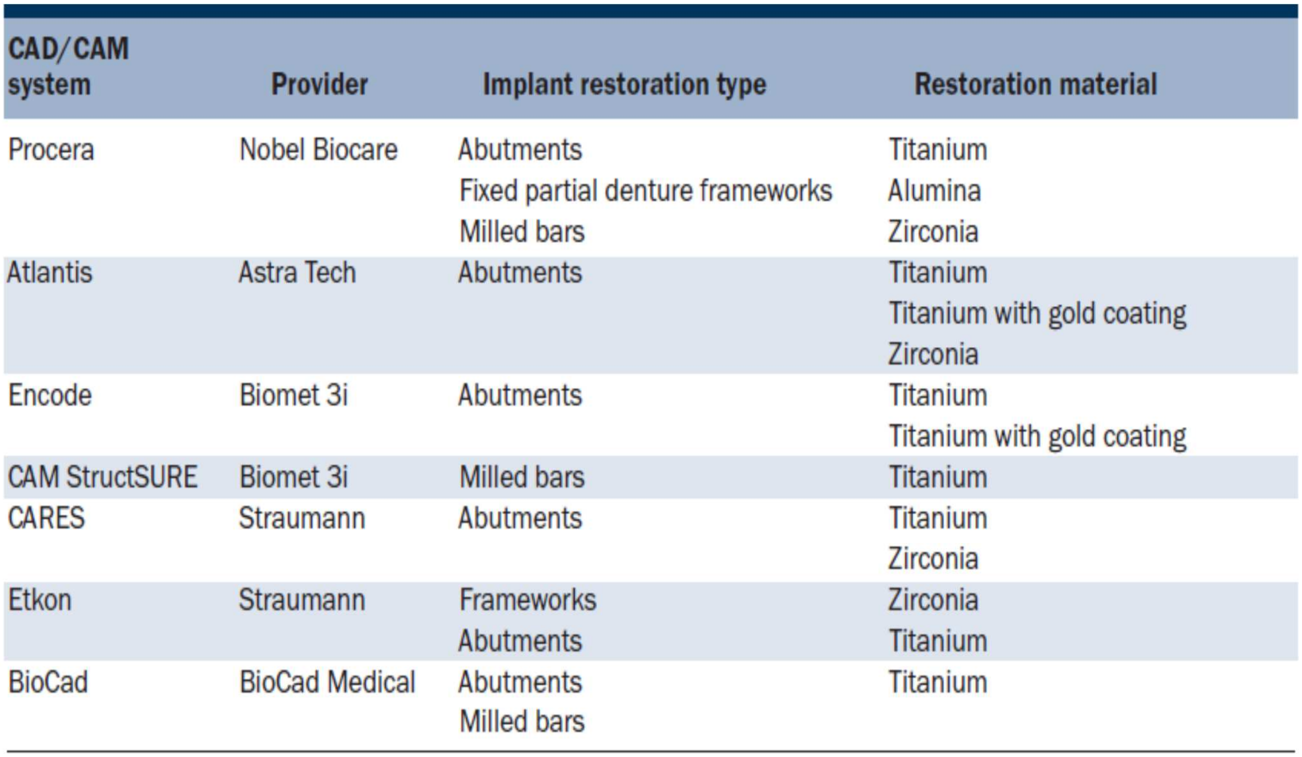
$$\text{Monoclinic} \overset{1173^\circ\text{C}}{\Leftrightarrow} \text{Tetragonal} \overset{2370^\circ\text{C}}{\Leftrightarrow} \text{Cubic}$$

Figure 3: Ranges of Stability for the Crystallographic Phases of Zirconia

At room temperature zirconia exists in monoclinic form. Addition of stabilizing oxides, like yttrium oxide, transforms the monoclinic form of zirconia to a metastable tetragonal phase with better mechanical properties. During application of applied loading, the metastable tetragonal phase transforms to the stable monoclinic phase. This transformation of zirconia (Fig.3) is accompanied by a localized volumetric expansion of 3%-4%[19], which acts as a barrier to crack propagation, which is known as the starting point for a catastrophic failure in ceramics. In dentistry, zirconia has been used for clinical applications such as crowns, frameworks for FPD's and for orthodontic brackets.[17] Reviewing the literature, one can find plenty of articles comparing abutment selection. Sailer et al reported several factors to be considered before selecting an abutment for the anterior region: smile line, biotype of the gingiva, color of neighboring teeth, as well as esthetic expectations of the patient.[21] Nakamura et al made a systematic review to assess zirconia abutments from various aspects. They concluded that zirconia abutments have the potential to be part of the everyday professional life because they show very good results in terms of plaque accumulation and periimplant tissue response.[22] In addition to this, they have good mechanical properties in terms of fracture resistance, especially when compared to alumina abutments. Yildirim et al quantified the fracture load of implant supported Al_2O_3 and ZrO_2 abutments restored with glass-ceramic crowns. They concluded that even though both groups exceeded the established values for maximum incisal forces reported in the literature (90 to 370 N), the zirconia abutments were more than twice as resistant to fracture as the alumina ones.[23] Similar results were recorded by Butz et al, who compared the survival rate and the failure mode of titanium, zirconia and alumina abutments after chewing simulation. They used abutments fixed on implants using gold alloy screws, torqued at 32Ncm, and then they exposed them to 1.2 million chewing cycles. They concluded that zirconia abutments performed similar to titanium abutments and can be used in anterior restorations.[16] On the other hand, Foong et al in a recent in vitro study, that simulated the masticatory forces through a loading device, concluded that 1-piece zirconia abutments exhibited significantly lower fracture resistance compared to titanium abutments. They also noticed that zirconia abutment fracture occurred before screw failure.[24]

1.4.4 Fabrication of abutments with CAD/CAM technology

CAD/CAM stands for Computer Aided Design/ Computer Assisted Manufacturing. Since its introduction in dentistry almost 22 years ago, it has played an important role in the evolution of dental technology.[25] CAD/CAM complements earlier technologies in order to increase the speed and simplicity of design and production of dental components. Abutments can be either stock or custom. The custom abutments can be of two types, cast custom and CAD/CAM custom[26] (Fig.4). Multiple studies have evaluated CAD/CAM abutments in dental patients. Henriksson and Jemt placed implants in the anterior maxillary region, thirteen of which received ceramic crowns cemented on ceramic abutments fabricated by Procera, while the rest received screw retained ceramic restorations.[27] Similarly, Canullo in a cohort study reported 25 patients who received 30 single-implant restorations in various oral regions. He used modified zirconia abutments with titanium metallic inserts for the final restorations.[28] Combining the results of both studies, there were a total of 53 abutments, with no significant failures or complications reported within the first year.



CAD/CAM system	Provider	Implant restoration type	Restoration material
Procera	Nobel Biocare	Abutments Fixed partial denture frameworks Milled bars	Titanium Alumina Zirconia
Atlantis	Astra Tech	Abutments	Titanium Titanium with gold coating Zirconia
Encode	Biomet 3i	Abutments	Titanium Titanium with gold coating
CAM StructSURE	Biomet 3i	Milled bars	Titanium
CARES	Straumann	Abutments	Titanium Zirconia
Etkon	Straumann	Frameworks Abutments	Zirconia Titanium
BioCad	BioCad Medical	Abutments Milled bars	Titanium

Figure 4: Summary of available CAD/CAM systems for dental abutments (2016).

Ferrari et al, in a recent controlled prospective clinical trial with 56 patients, compared CAD/CAM abutments from titanium, titanium nitride and zirconia. Five failures in a total of 89 restorations were reported for zirconia abutments, and the author concluded that zirconia abutments should be avoided, especially for posterior restorations.[29]

1.5 Microgap between implant and abutment

One of the most important features of screw retained implant restorations is the interface between the actual fixture and the abutment that is attached to it. This is because the forces that are applied during mastication are concentrated right on the interface of the implant abutment assembly. During occlusal loading of an implant supported restoration, the region around the abutment screw head is the area of the highest torque and stress concentrations, and it has been demonstrated to be the most critical region for the stability of ceramic abutments.[23,30] The mechanical interaction of these two components will determine the long term survival of the whole prosthesis. Even if not visible clinically, there is always a microgap in the interface between the implant and the abutment at the microscopic level. The larger it gets, the more prone is the prosthesis to catastrophic failure. Multiple studies exist in the literature for the evaluation of the microgap between implant and abutment.[31] Baixe et al used four different systems of zirconia abutments and measured the microgap using scanning electron microscopy. They found that the microgap of these abutments were lower than for titanium abutments. They also showed that the microgap is affected by several factors, like the milling method or the screw torque value.[32]In addition to this, the importance of the microgap is obvious because lack of precise fit can lead to bacterial colonization and eventually to inflammation and bone loss,[33] especially in the anterior area, where the margin of the restoration is located subgingivally for esthetic reasons. Gil et al showed that bacteria accumulated on the implant surfaces can affect mechanical properties, i.e. the flexural strength and the fatigue resistance through a process that is termed as corrosion fatigue fracture.[34] It is obvious that a larger microgap in the interface between implant and abutment can enhance this chemical process.

1.6 Wear in the interface between implant and abutment

As previously mentioned, an increased microgap can jeopardize the long term success of the implant restoration. Taking into consideration that the masticatory system can create large forces, we need to evaluate the interface between implant and abutment under loading. Stimmelmayr et al compared the wear of titanium implants when attached to titanium and zirconia abutments, and they found that the wear at the interface for titanium-zirconia is higher than this for titanium with titanium.[35,36] However, in their results they did not record any prosthetic failure, such as screw or abutment loosening. Regarding the same topic, Klotz et al, in a pilot study, showed that zirconia abutments can cause more implant wear than titanium under cyclic loading, especially during the initial cycles. Through an image analysis method, they confirmed titanium transfer to the zirconia abutment, that increased with the loading cycles.[37] The initial rate of wear was 4.5 times greater with zirconia than for titanium specimens and they attributed this difference to the hardness of zirconia (1600 to 2000 Vickers), which is approximately 10 times higher than that of commercially pure titanium (258 Vickers).[37]

1.7 Modified zirconia abutment

The increased wear between zirconia abutment and titanium implant can put at risk the whole restoration because of the disruption of the intaglio surface of the implant via permanent deformation. Furthermore, it can lead to increased micromovement and possible abutment loosening or even worse, abutment fracture. Karl et al, using a novel mechanical approach, evaluated the micromotion of Computer Aided Design/ Computer Assisted Manufactured (CAD/CAM) zirconia and titanium abutments. They found that zirconia abutments showed less micromotion compared to the titanium ones, but concluded there does not seem to exist any perfect implant geometry or fabrication technique for the abutment that would result in no detectable micromotion.[38]

Recently, in the market a modified zirconia abutment was released. The difference between this and traditional zirconia abutments is the titanium insert that the zirconia part is attached to (Fig.5). In this way, there is similar material interaction (titanium vs titanium) in the critical interface between implant and abutment.

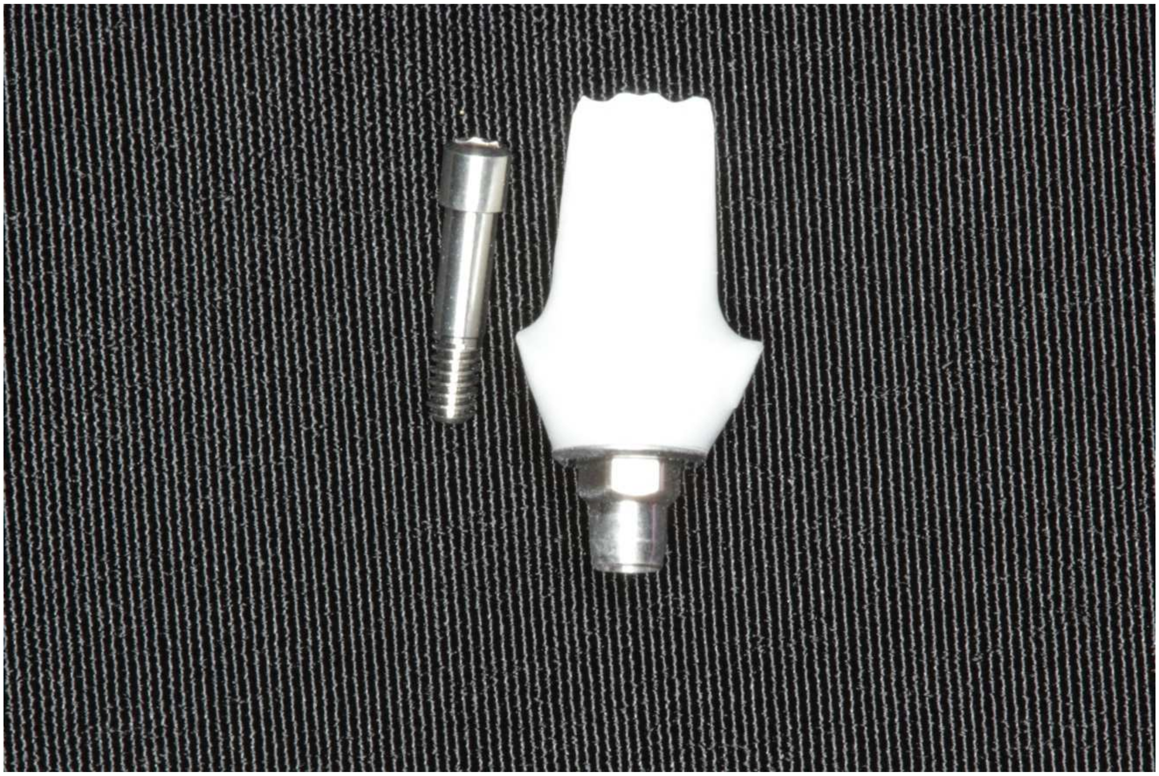


Figure 5: Modified CAD/CAM zirconia abutment fabricated from Procera.

There are two ways of attachment of the zirconia part to the titanium insert that is being screwed to the implant fixture. It can be attached either through friction fit between the two materials or it can be bonded. Sailer et al compared different types of zirconia abutments (one- and two- piece) and connections (internal and external) in terms of fracture load. One group consisted of the modified zirconia abutment from Procera (Nobel Biocare) with an internal connection implant type. Their results showed that internal connection implants achieved superior strength and the highest bending moments.[39] The metallic secondary component of the modified zirconia abutment seemed to be advantageous to the transfer of forces. In addition to this, Garine et al compared the rotational misfit between four commercially available abutment types, and found that all ceramic abutments without metal collar showed greater rotational misfit than the ones consisting of zirconia stabilized on a titanium sleeve.[40]

1.8 Purpose and Significance of the study

The purpose of this study is to compare the microgap between CAD/CAM fabricated modified zirconia abutments to CAD/CAM fabricated titanium abutments under cyclic loading in three different intervals. Moreover, this study will compare the microgap between the zirconia component and the titanium insert after cyclic loading. To the author’s knowledge, this is the first study to evaluate the latter and the goal is to add to the existing scientific knowledge regarding CAD/CAM abutments in the anterior region. The controversy between mechanical properties and esthetic advantages has always been a point of interest in dentistry. Increased microgap in the interface of the implant abutment assembly or between zirconia component and titanium insert will negatively impact the long term efficacy of these types of restorations.

1.9 Specific Aims and Hypothesis

The goals of this study are:

Specific Aim 1: Compare the microgap in the interface between implant and abutment for titanium and modified zirconia abutments after cyclic loading.

Specific Aim 2: Compare the microgap between zirconia component and titanium insert of the modified zirconia abutments after cyclic loading.

Hypothesis 1: The microgap between implant and abutment is greater for the zirconia group compared to the titanium group.

Null hypothesis 1: There is no difference in the microgap between implant and abutment among the groups.

Hypothesis 2: The microgap between zirconia component and titanium insert increases through the cyclic loading process.

Null Hypothesis 2: There is no difference in the microgap between zirconia component and titanium insert through the cyclic loading process.

Chapter 2: Materials and Methods

2.1 Design

This study is a laboratory experiment, with the implant-abutment assemblies randomly assigned to respective groups.

2.2 Materials

Sixteen implant-abutment assemblies were included in the study. The implants were not available for clinical use due to expired sterilization date and they were donated by Biomet 3i (Palm Beach Gardens, Florida). All sixteen implants were made from commercially pure titanium (FULL OSSEOTITE Certain)[41], and had diameter of 5 mm with a restorative platform of 4.1 mm due to the platform switch design (Fig.6).

Figure 6: Biomet 3i Full Osseotite implant.[41]

A custom abutment (Fig.7) for an anterior restoration was fabricated from pattern resin material (GC America Inc. Alsip, IL), and was used as the model for the fabrication of all the CAD/CAM custom abutments.

Figure 7: Custom resin abutment.

The custom resin abutment was used as a prototype from which all abutments were fabricated. CAD/CAM technology was used to copy the resin prototype and fabricate sixteen custom abutments, which were used in the study. Eight of those were from commercially pure titanium grade 4 and the rest were made from a zirconia (Y-TZP) component cemented to a titanium insert (Fig.8,9). All specimens were of the same configuration, which resembled an abutment for the restoration of a maxillary central incisor.

Figure 8: CAD/CAM titanium and modified zirconia abutments.

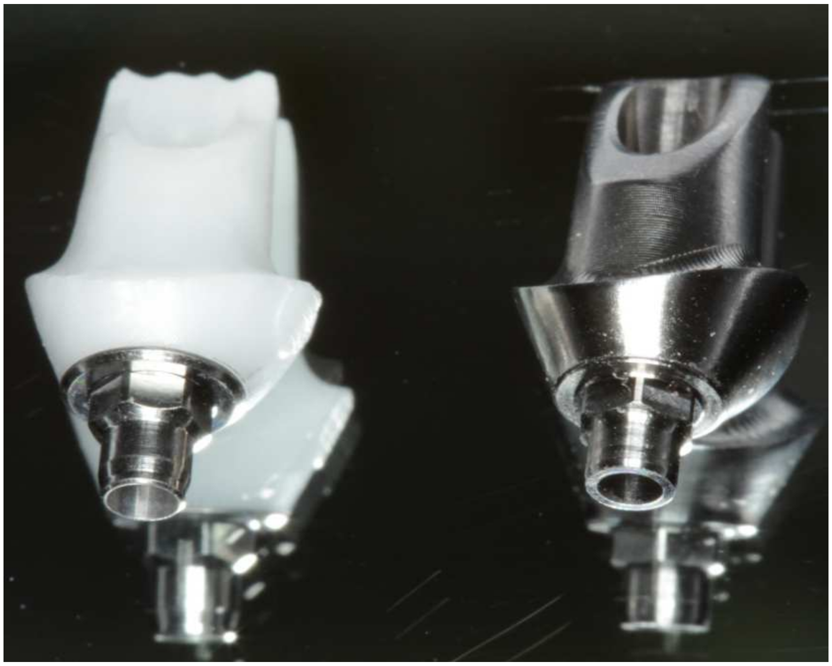


Figure 9: CAD/CAM titanium and modified zirconia abutments.

As far as materials are concerned, in this study clear orthodontic autopolymerising resin (Dentsply, Caulk, York PA) was used to mount the specimens, as will be explained in the setting section.

2.3 Instrumentation

To conduct this experiment multiple instruments were used:

1) Loading test device (Fig.10) from NOVA Southeastern University laboratory, which consists of four pistons that can apply predetermined force under predetermined frequency to specimens mounted in it.

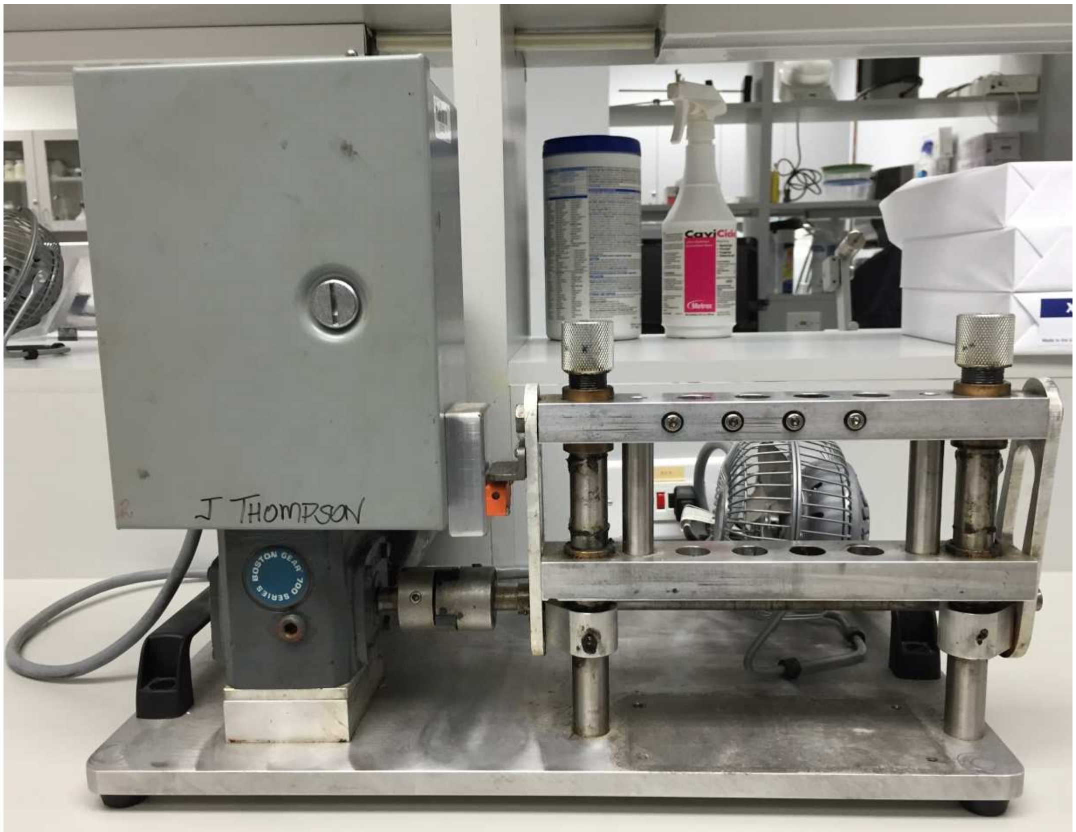


Figure 10: NOVA Southeastern University loading device.

2) Isomet 1000 Precision Cutter (Buehler, IL, USA) (Fig.11), used to section the samples lengthwise at a predetermined speed.

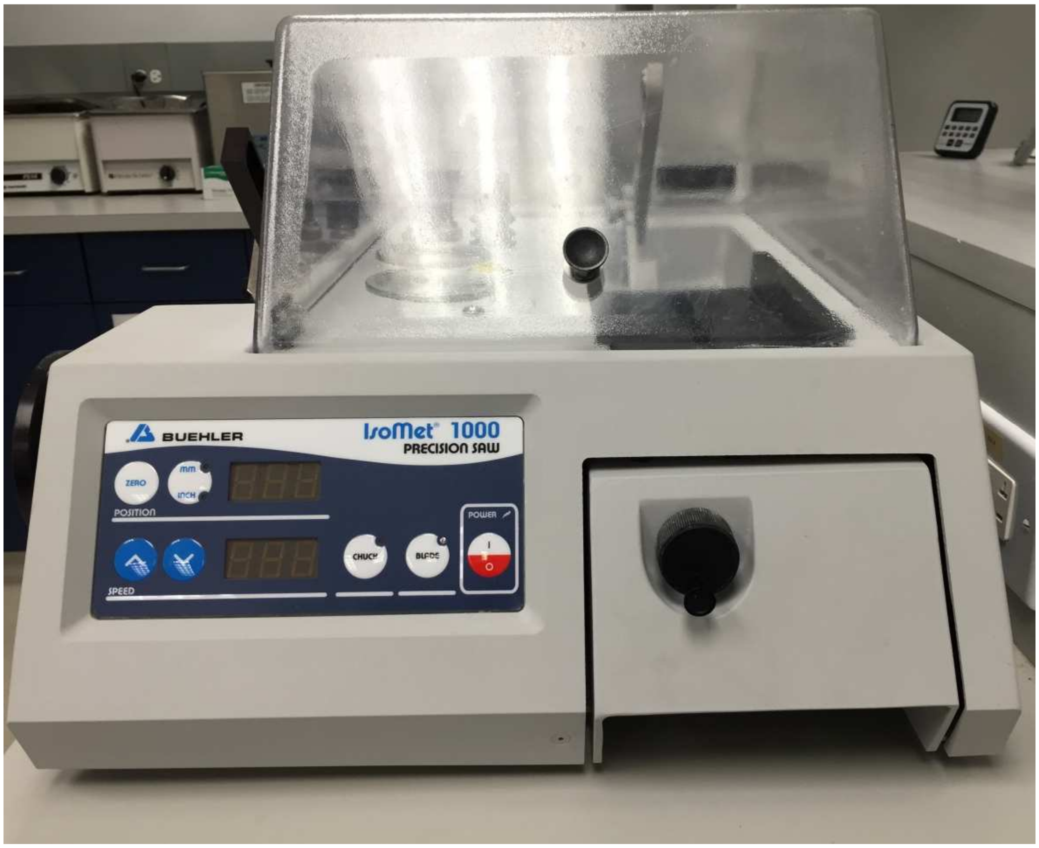


Figure 11: Isomet 1000 Precision Cutter.

3) Scanning Electron Microscope (FEI Quanta 200, Columbus, Ohio,USA) (Fig.12), which is used to produce images of a sample by scanning it with a focused beam of electrons and can achieve a resolution better than 1 nanometer.

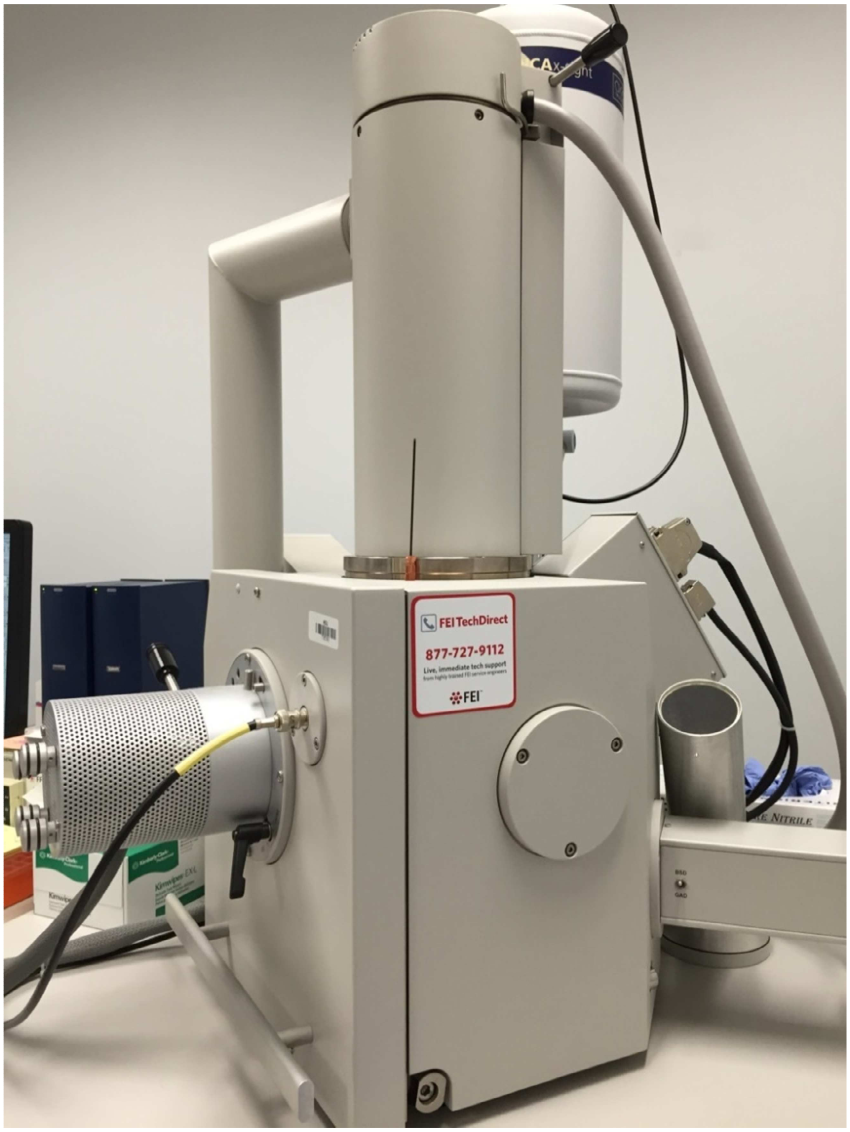


Figure 12: Scanning Electro Microscope.

4) A mechanical calibration device (Instron 8841, Canton, MA, USA) (Fig.13) was used to set the spring load in 100N for each loading piston (Fig.14) used in the cyclic loading device.

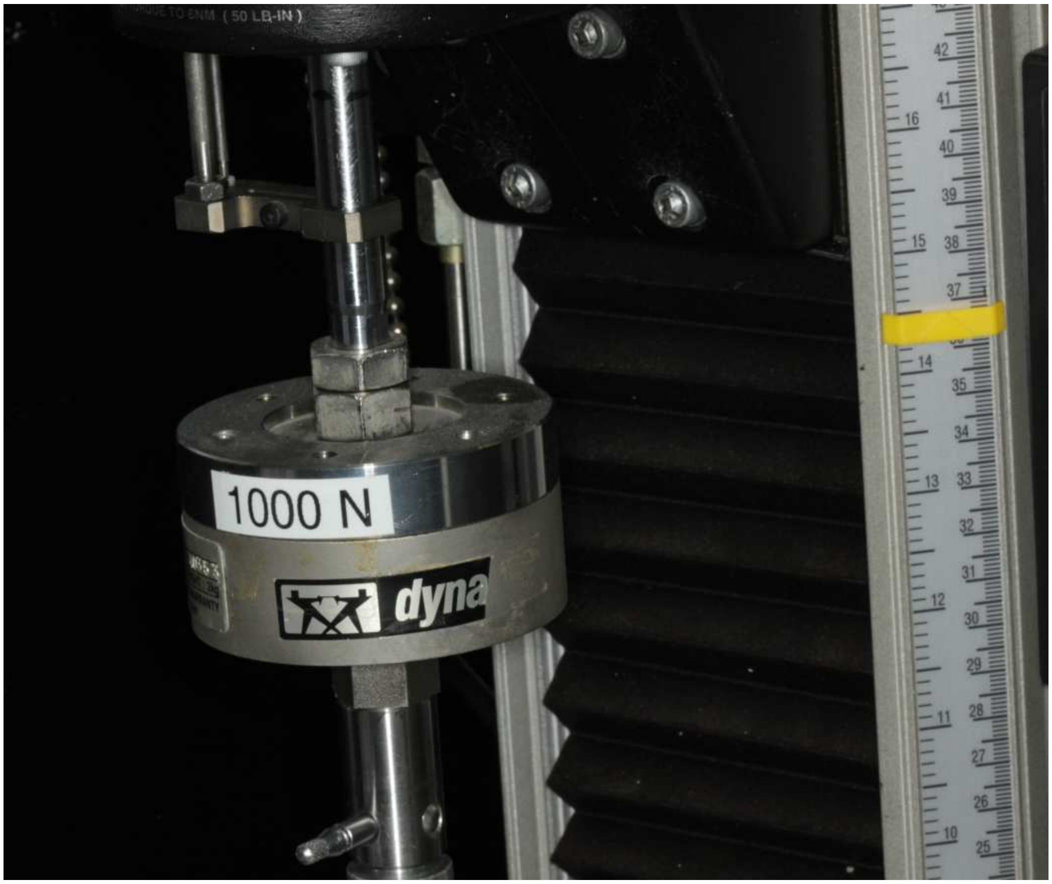


Figure 13: Mechanical calibration machine.

Figure 14: Loading piston for fatigue stimulation device.

2.4 Experiment setting

The sixteen CAD/CAM abutments were screwed to the implant fixtures using a torque of 25 Ncm. A new Biomet 3i calibrated implant wrench was used to confirm the recommended torque for each abutment. Autopolymerising Caulk orthodontic resin (Dentsply, York, PA) was mixed according to the manufacturer recommendations and the sixteen implant-abutment assemblies were embedded in it. After the resin set, the specimens were secured on plastic bases using super glue (Fig.15, 16).

Figure 15: Mounted titanium and modified zirconia abutments at 30 degree angulation.

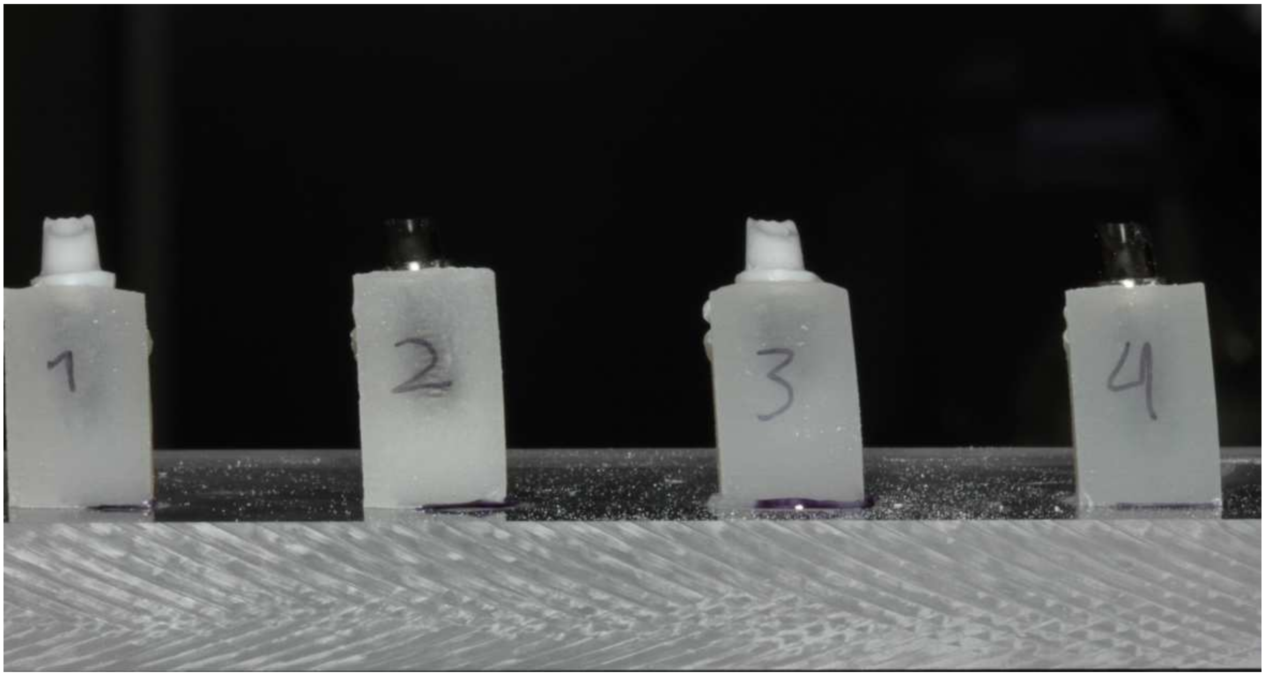


Figure 16: Mounted titanium and modified zirconia abutments at 30 degree angulation.

Each one of those plastic bases consisted of two CAD/CAM titanium and two modified zirconia abutments.

Each group was mounted in the loading platform of a testing machine at 30 degrees off-axis angulation according to similar studies.[36,37,39]

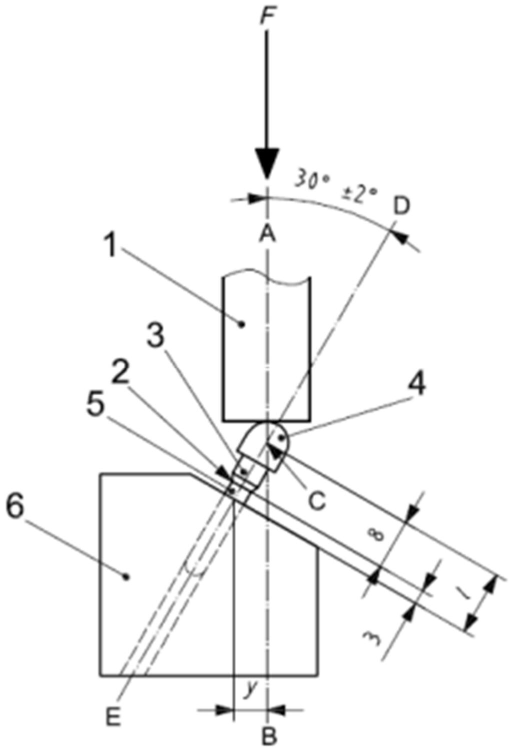


Figure 17: Schematic depiction of the mounted specimen.

The universal international standard ISO 14801[42] for implant loading tests was used for this project (Fig.17), according to which an endosseous implant includes no pre-angled connecting parts and is clamped such that its axis makes a 30º ± 2º angle with the loading direction of the testing machine. The 30 degree angulation is used because it approximately represents the loading that is being applied in the lingual aspect of a maxillary central incisor during mastication (Fig.18).

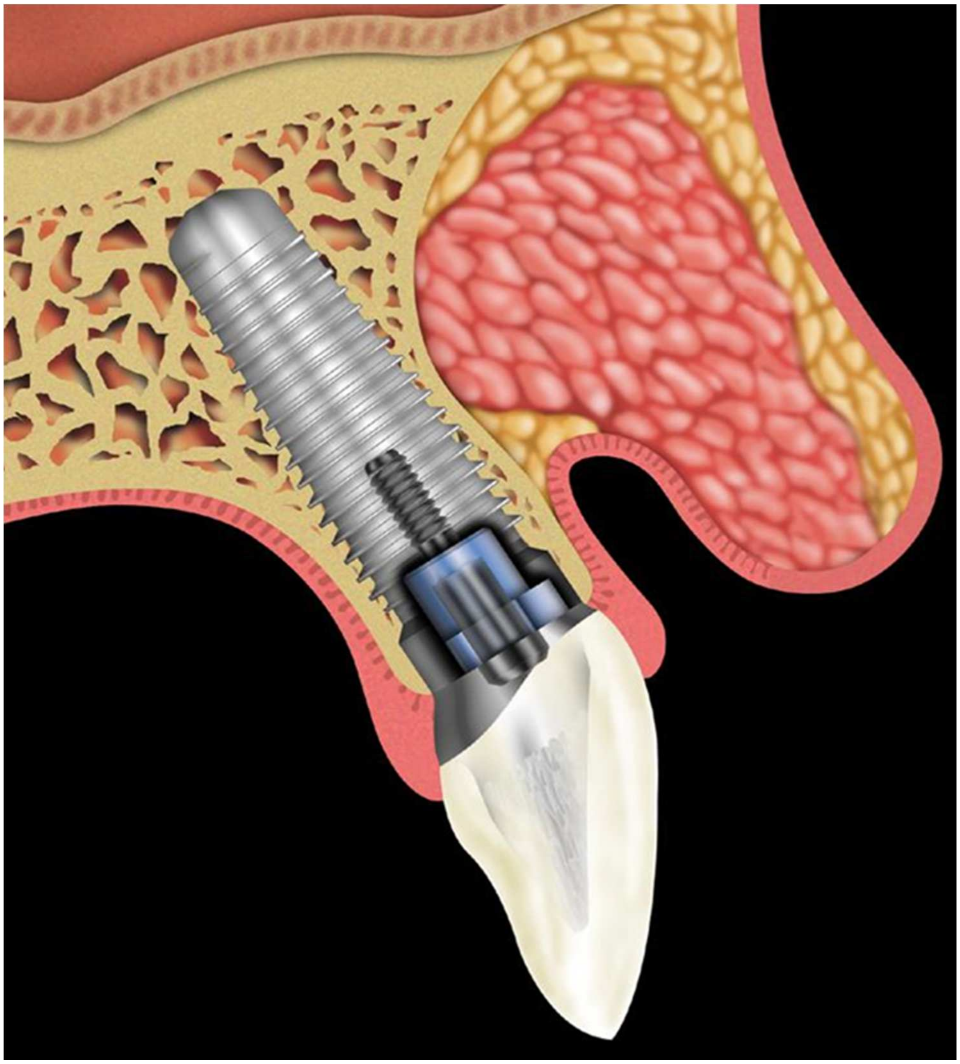


Figure 18: Schematic depiction of maxillary central incisor.

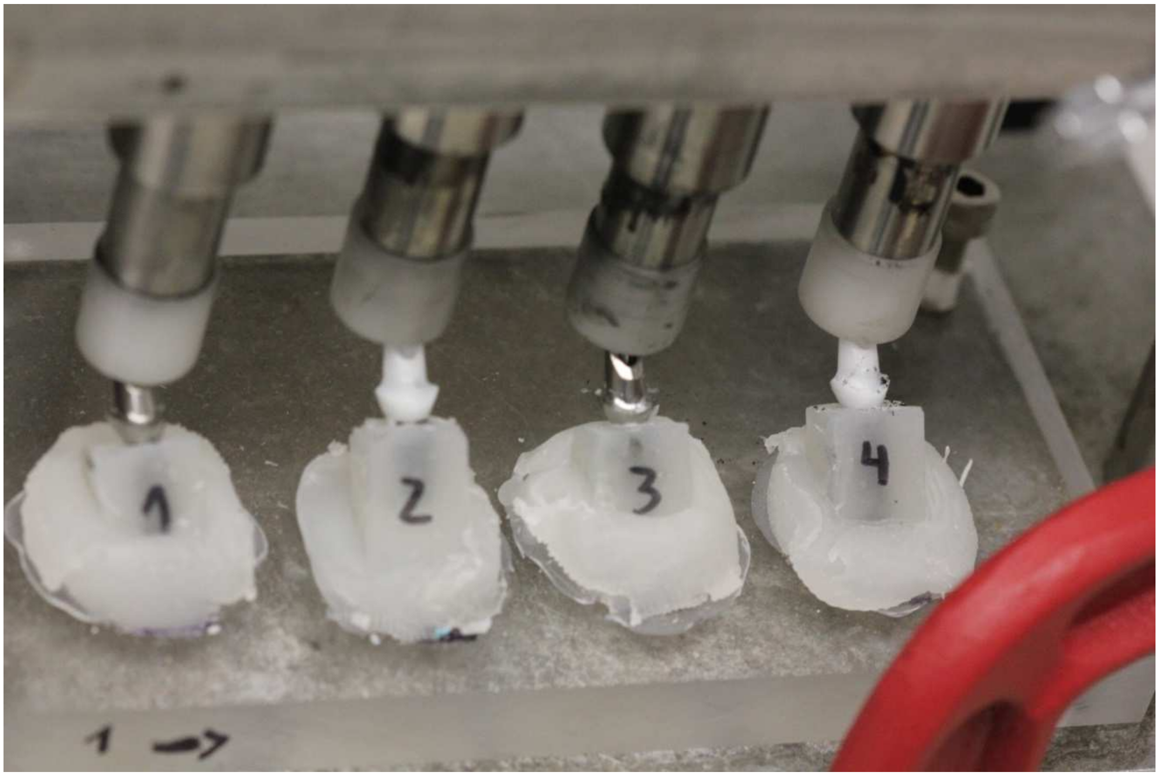


Figure 19: Specimens mounted and secured at the testing device during loading. Titanium specimens #1,3, Zirconia specimens #2,4.

The four pistons were calibrated to a predetermined force of 100 N, and a frequency of 1.2 Hz was used (Fig.19). This value is within the normal limits for applied force during mastication in the lingual aspect of a maxillary central incisor of a Class I patient. The groups were defined as follows (Fig.20):

- The control group was not loaded.
- Group 1 was loaded for 100,000 cycles.
- Group 2 was loaded for 250,000 cycles.
- Group 3 was loaded for 500,000 cycles.

According to Graf, the average person performs 1350 chewing strokes per day in 3 meals; this means that Group 3 (500,000 cycles) corresponds approximately to almost 1 year of eating strokes.[43]

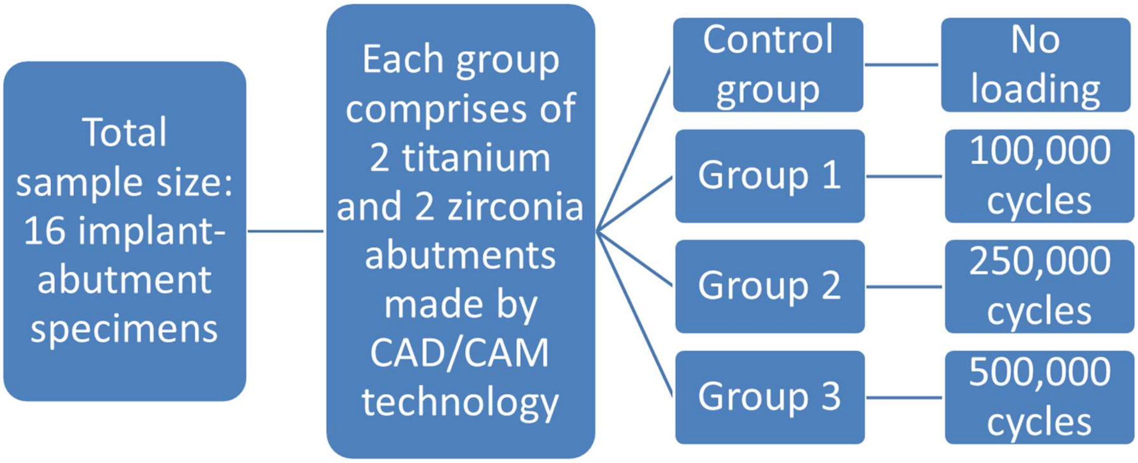


Figure 20: Sample group breakdown.

After the loading test was completed, the specimens were detached from the plastic base and secured with ortho autopolymerising resin (Caulk, Dentsply, York, PA). A straight line was marked that would be used as a guide for the sectioning process. After that, the specimens were mounted on a Precision Saw in order to be sectioned lengthwise (Fig.21,22).

Figure 21: Specimen secured after cycle loading.

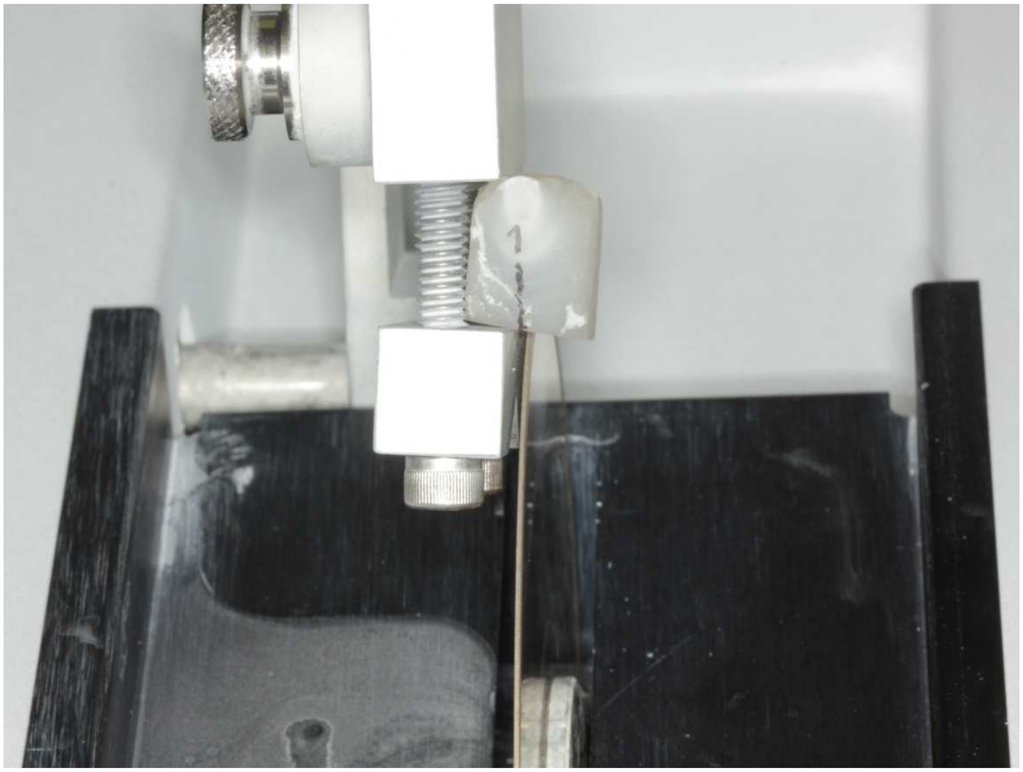


Figure 22: Specimen mounted in the Precision Saw.

The samples that were produced from the sectioning process (Fig.23) were coated with gold (Fig.24) that provides an enhanced image at the microscopic level, by increasing electrical conduction. Scanning Electron Microscopy was used to take micrographs of the specimens after maximizing the image of the interface between implant and abutment.

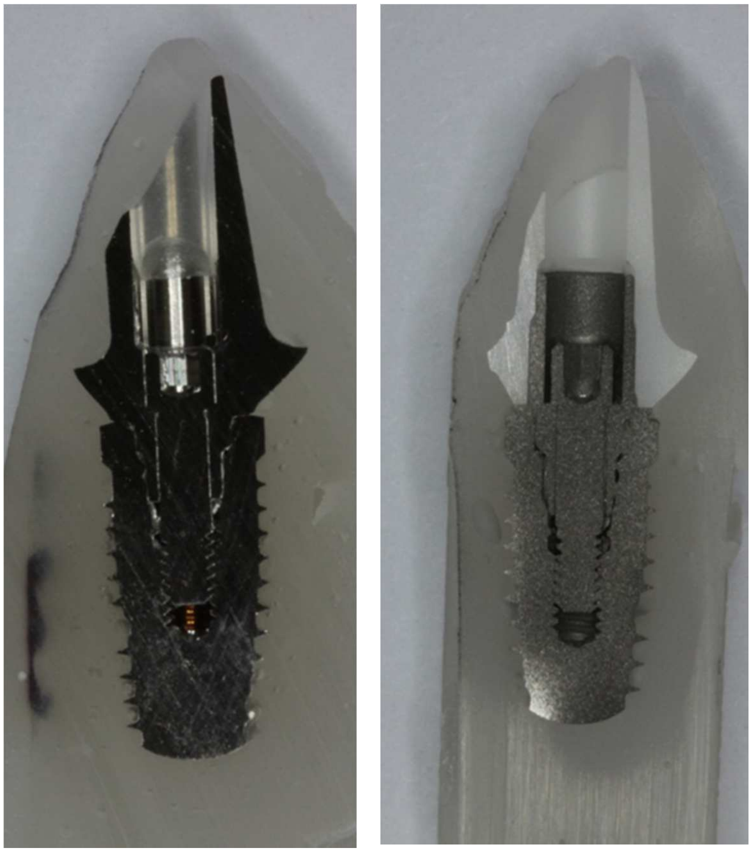


Figure 23: Specimens after sectioning.

Figure 24: Specimens coated with gold for SEM imaging.

SEM image analysis software was used to save images with a magnification of 28x. The images were of two types:

A) For the CAD/CAM titanium abutments, the images depicted the interface between the implant and the abutment.

B) For the CAD/CAM modified zirconia abutments, the images depicted the interface between implant and abutment, as well as the interface between the zirconia component and the titanium insert.

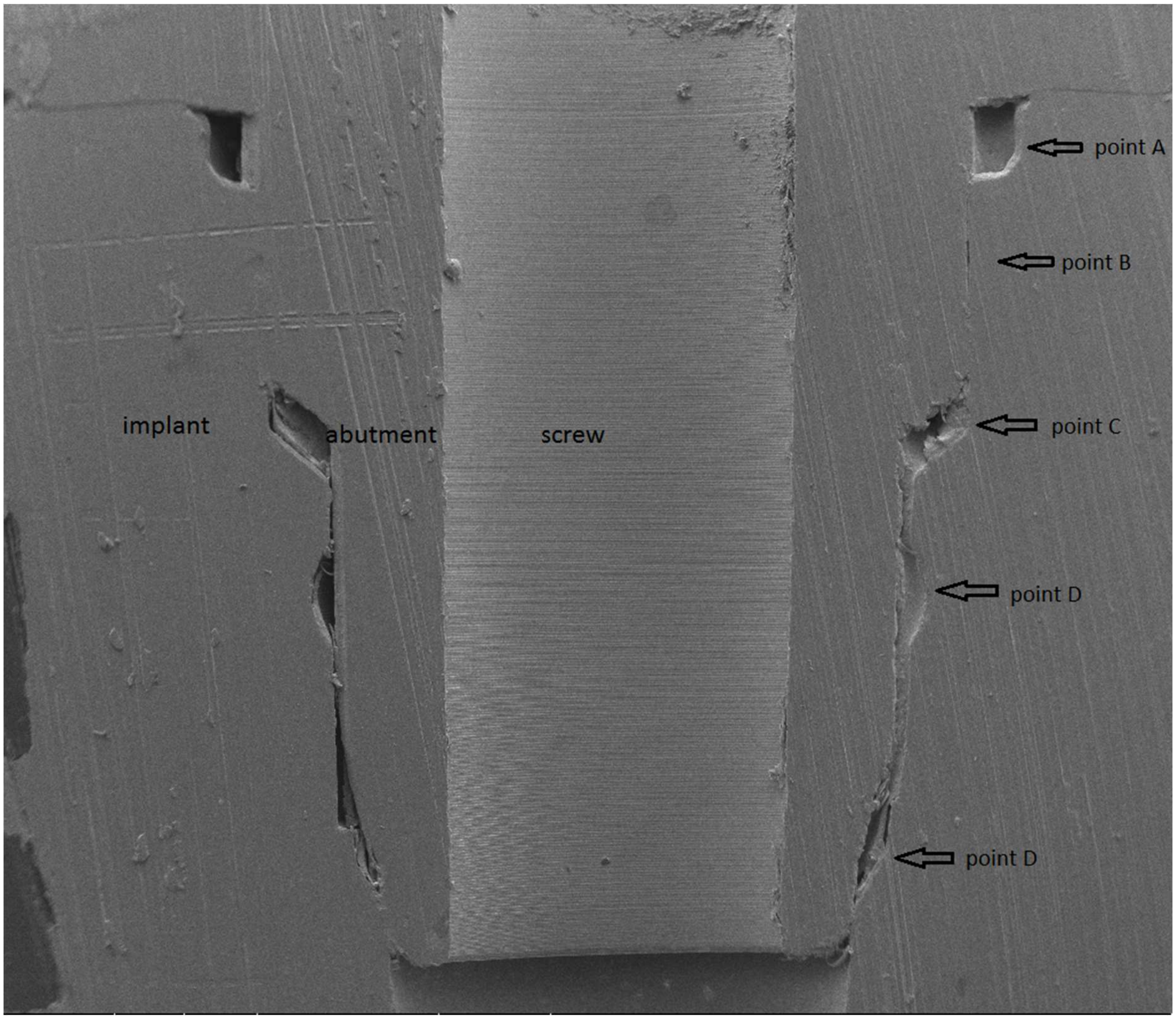


Figure 25: SEM image for the implant-abutment interface.

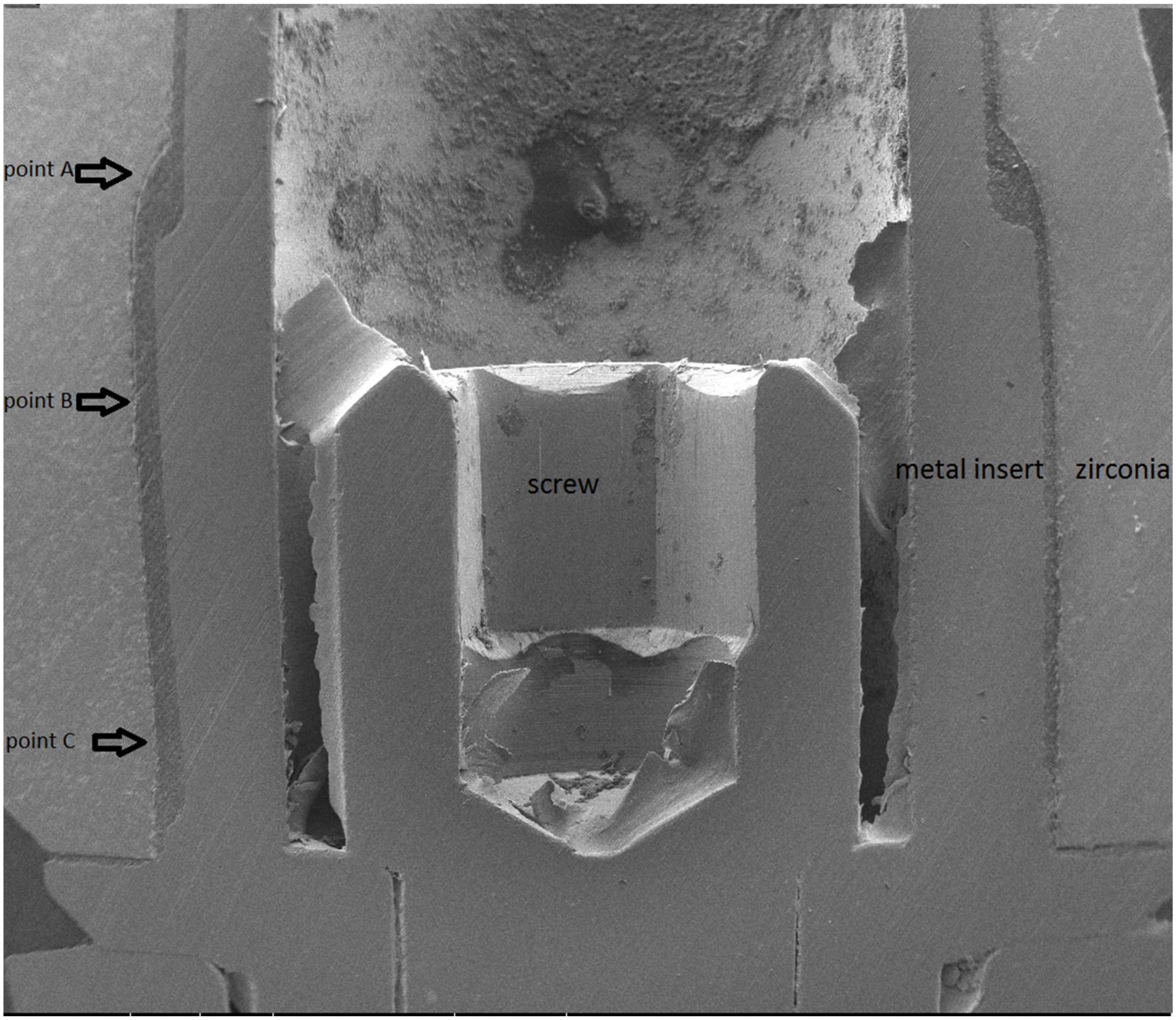


Figure 26: SEM image for the interface between zirconia component and titanium insert.

For the first hypothesis of the study, five points (Fig. 25) were randomly selected along the interface between implant and abutment and the mean microgap was assessed for all the specimens.

For the second hypothesis of the study, three points (Fig.26) were randomly selected along the interface between the zirconia component and the titanium insert and the microgap was assessed for all specimens.

2.5 Dependent and Independent Variables:

The dependent variables of this study are:

A) The microgap at the interface between implant and abutment.

B) The microgap at the interface between the zirconia component and the titanium insert.

The independent variable of this study is the cyclic loading for three different intervals.

2.6 Statistical data management and analysis

The statistical data were gathered from all the specimens and they were analysed using SPSS software (IBM, NY).

For specific aim #1, comparison of microgap at the interface between implant and abutment, descriptive statistics were performed to evaluate the mean and standard deviation values for CAD/CAM titanium and modified zirconia abutments. Analysis of Variance was used to compare the microgap between the two experimental materials and the three intervals of cyclic loading.

For specific aim #2, comparison of microgap at the interface between the zirconia component and titanium insert, descriptive statistics were performed to evaluate the mean and standard deviation values for CAD/CAM modified zirconia abutments. Analysis of Variance was used to compare the microgap between the three intervals of cyclic loading in the three points of measurement.

Differences were considered statistically significant when the P value was less than .05.

Chapter 3: Results

3.1 Loading testing results

All implant-abutment assemblies survived off-axis loading except one CAD/CAM titanium abutment in Group 3 (500,000 cycles), which failed catastrophically. The abutment fractured in the critical coronal interface with the implant after approximately 350,000 cycles.

Figure 27: Fractured titanium specimen.

The fractured specimen (Fig.27) was examined in the microscope at high magnification (34x) and showed excessive screw deformation (Fig.28) and an increased microgap (338 microns).

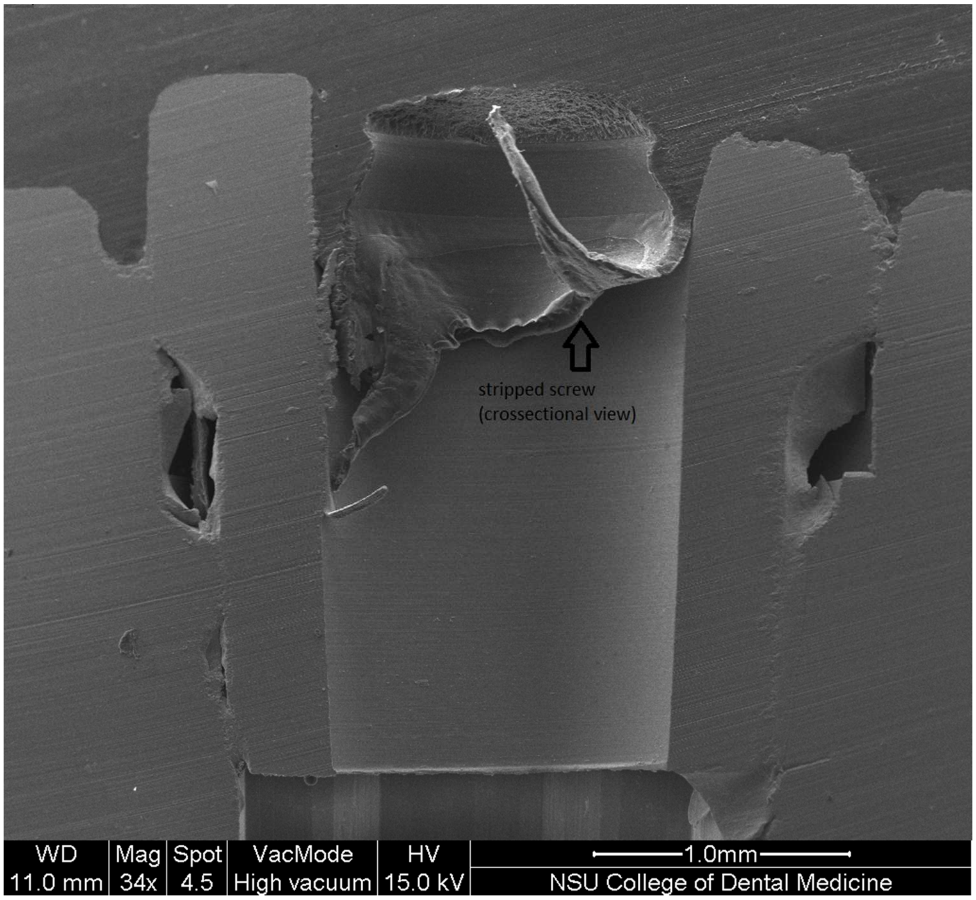


Figure 28: SEM image of fractured specimen.

3.2 Results for specific Aim #1

The first specific aim of this pilot study is to compare the microgap of the interface between CAD/CAM titanium and modified zirconia abutments in three intervals.

Microgap for titanium (microns)	Mean	Standard Deviation
Control Group	61.37	15.03
Group 1	73.60	10.46
Group 2	60.01	1.70
Group 3	54.61	-

Table 1: Microgap for CAD/CAM titanium abutments.

The mean microgap for CAD/CAM titanium abutments (Table 1) was 61.37 microns for the control group, 73.06 microns for Group 1 (100,000 cycles), 60.01 for Group 2 (250,000 cycles) and 54.61 for Group 3 (500,000 cycles). Obviously Group 3 had only one sample because as mentioned before the second fractured before completing the loading cycle test. There was no statistically significant difference between the CAD/CAM titanium abutments (P>0.05).

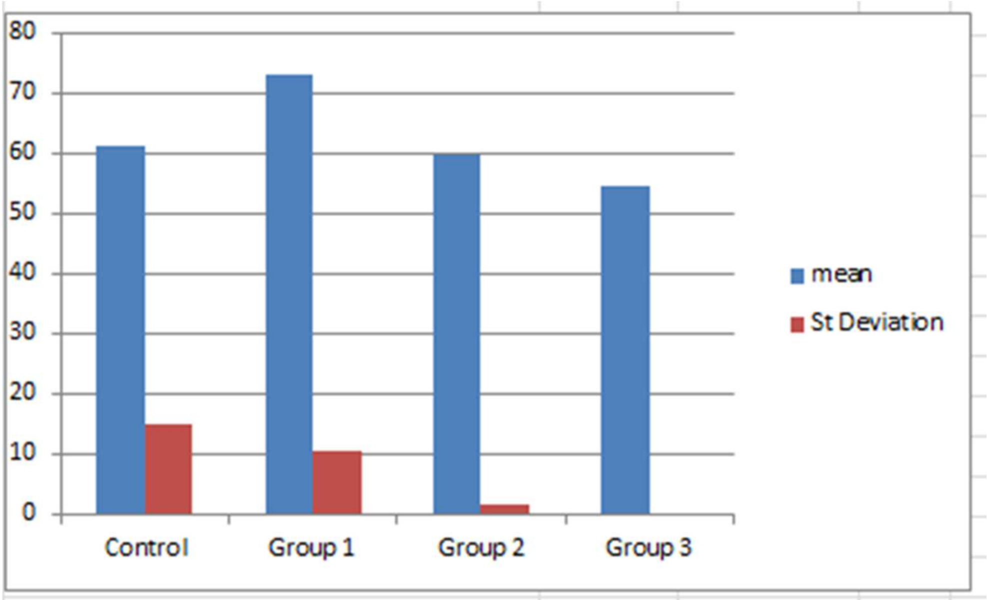
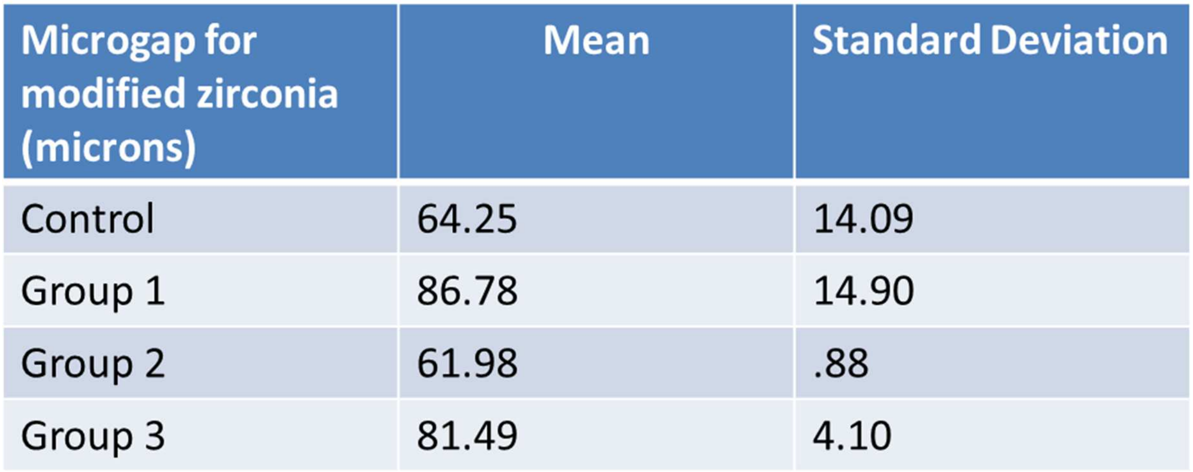


Figure 29: CAD/CAM titanium abutments microgap.

As far as the CAD/CAM modified zirconia abutments are concerned, the mean microgap in the interface between implant and abutment (Table 2) was 64.25 microns for the control group, 86.78 micorns for Group 1 (100,000 cycles), 61.98 microns for Group 2 (250,000 cycles) and 81.49 microns for Group 3 (500,000 cycles).



Microgap for modified zirconia (microns)	Mean	Standard Deviation
Control	64.25	14.09
Group 1	86.78	14.90
Group 2	61.98	.88
Group 3	81.49	4.10

Table 2: Microgap for CAD/CAM modified zirconia abutments.

There was no statistically significant difference between the CAD/CAM modified zirconia abutments in the three intervals of cycle loading (P>0.05).

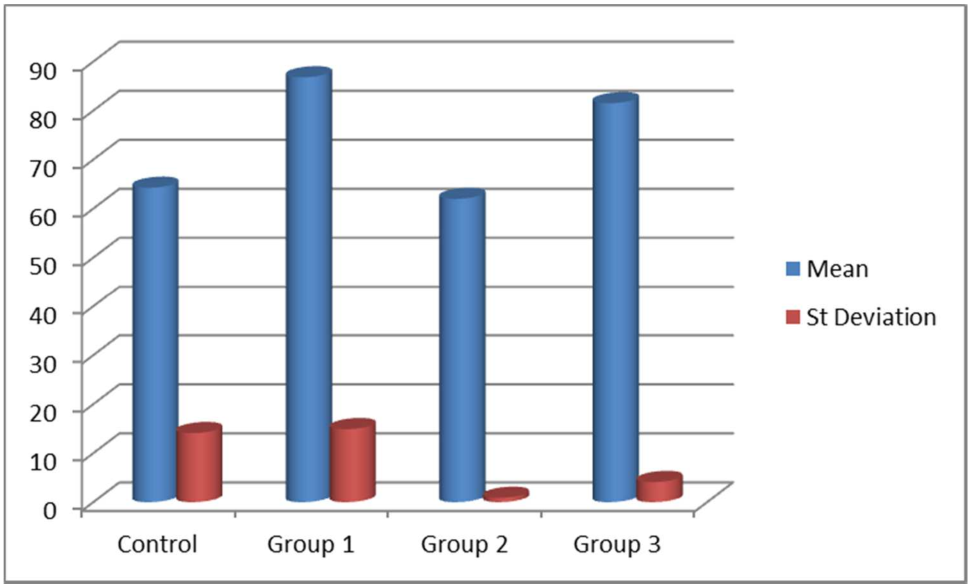


Figure 30: Microgap for CAD/CAM modified zirconia abutments.

Comparing the mean values of the microgap between the two types of abutments (titanium and modified zirconia), no statistically significant difference was found; this can make the modified zirconia abutments as a viable option for further use.

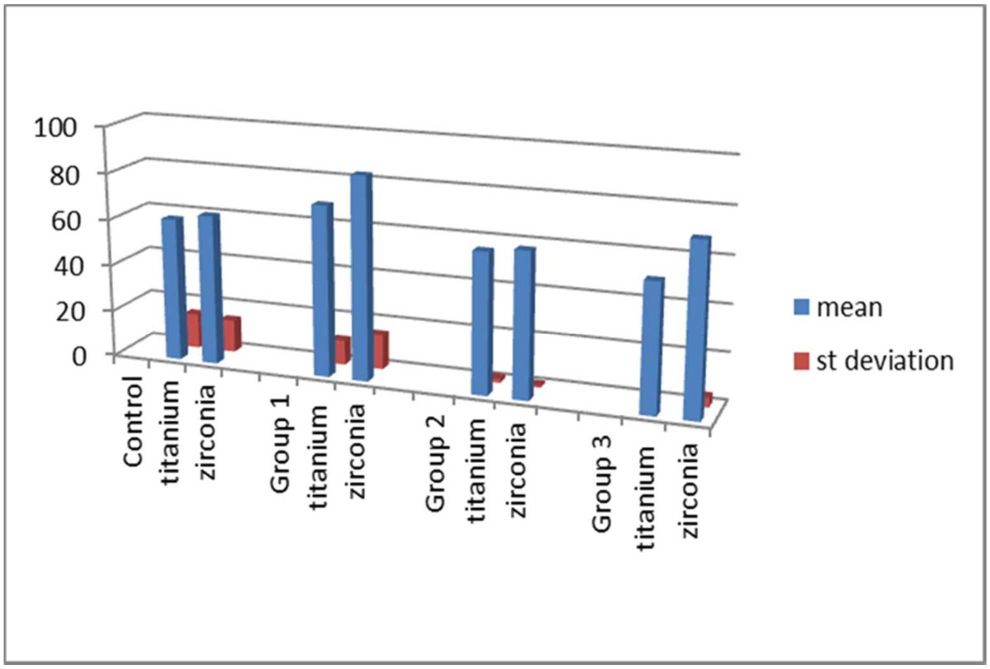


Figure 31: Microgap between the two types of abutments.

3.3 Comparison in each point of measurement

The fractured CAD/CAM titanium abutment was the main reason that we proceeded to the analysis and statistical comparison between the five points of measurement (Fig.32) along the interface between implant and abutment.

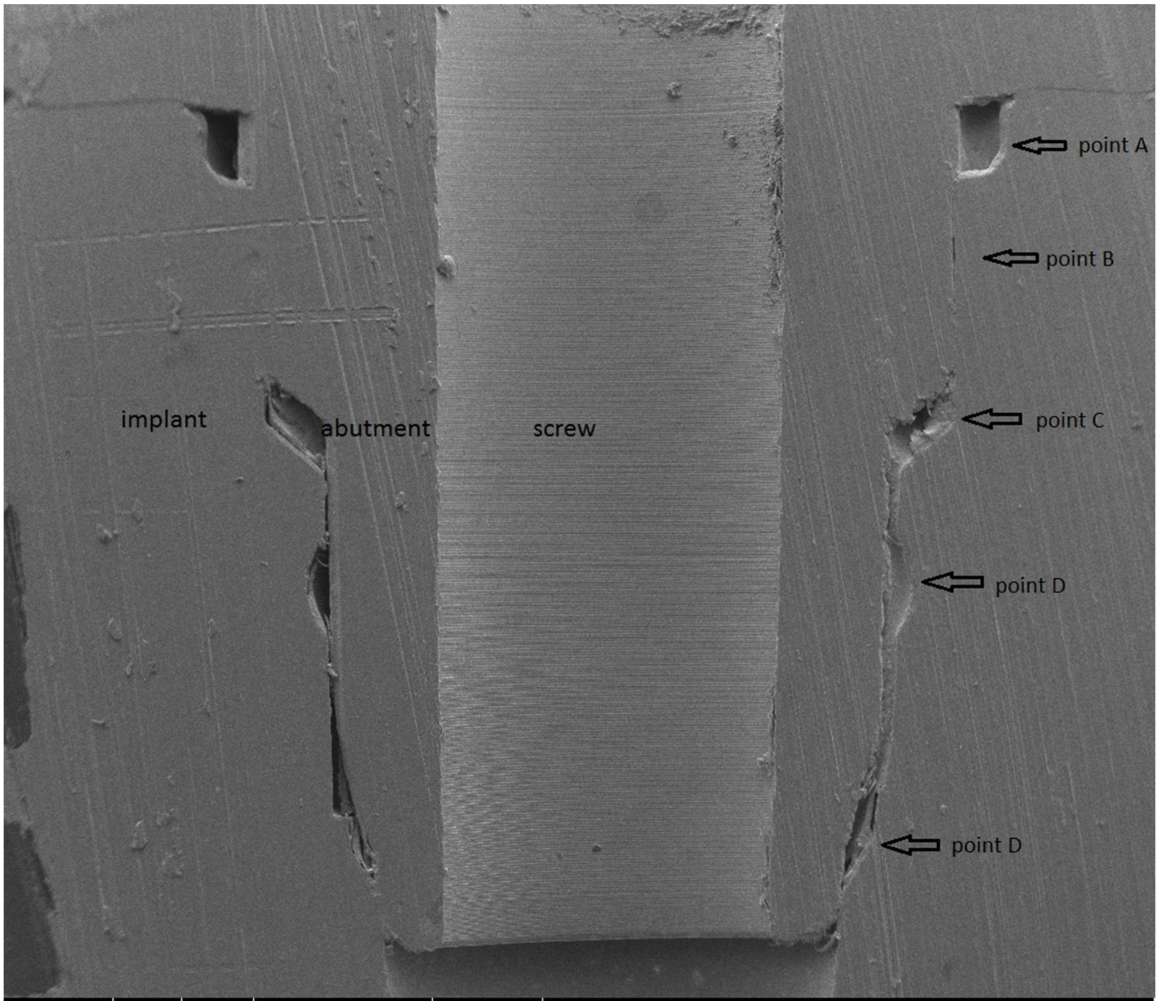


Figure 32: Five points of measurement along the interface.

The five points were named A, B, C, D, E starting from the most coronal to the most apical. No statistically significant difference was found between the points except for point C (Fig.33). More specifically, Group 2 (250,000 cycles) and Group 3(500,000 cycles) showed a statistically significant difference in the microgap at point C during the loading process.

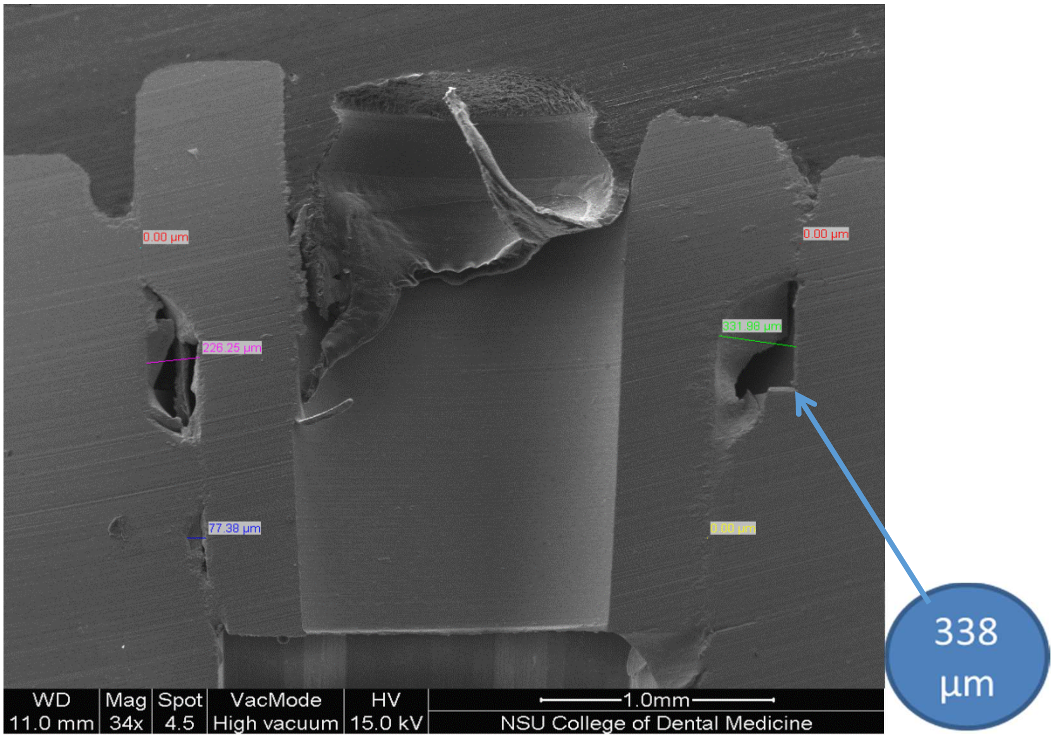


Figure 33: Point C in fractured specimen along with values in microns.

In Group 3, this statistical difference was anticipated because of the fractured specimen that would have an increased microgap, but finding the same statistical differences in Group 2 shows that this location along the interface is one where high stress is concentrated.

3.4 Results for Specific Aim #2

The specific aim of this pilot study was to compare the microgap in the interface of the zirconia component, which is cemented on a titanium insert. To the author's knowledge, this is the first study to make this comparison. For this comparison, 3 points of measurement were used, named A, B and C starting from most coronal to most apical.

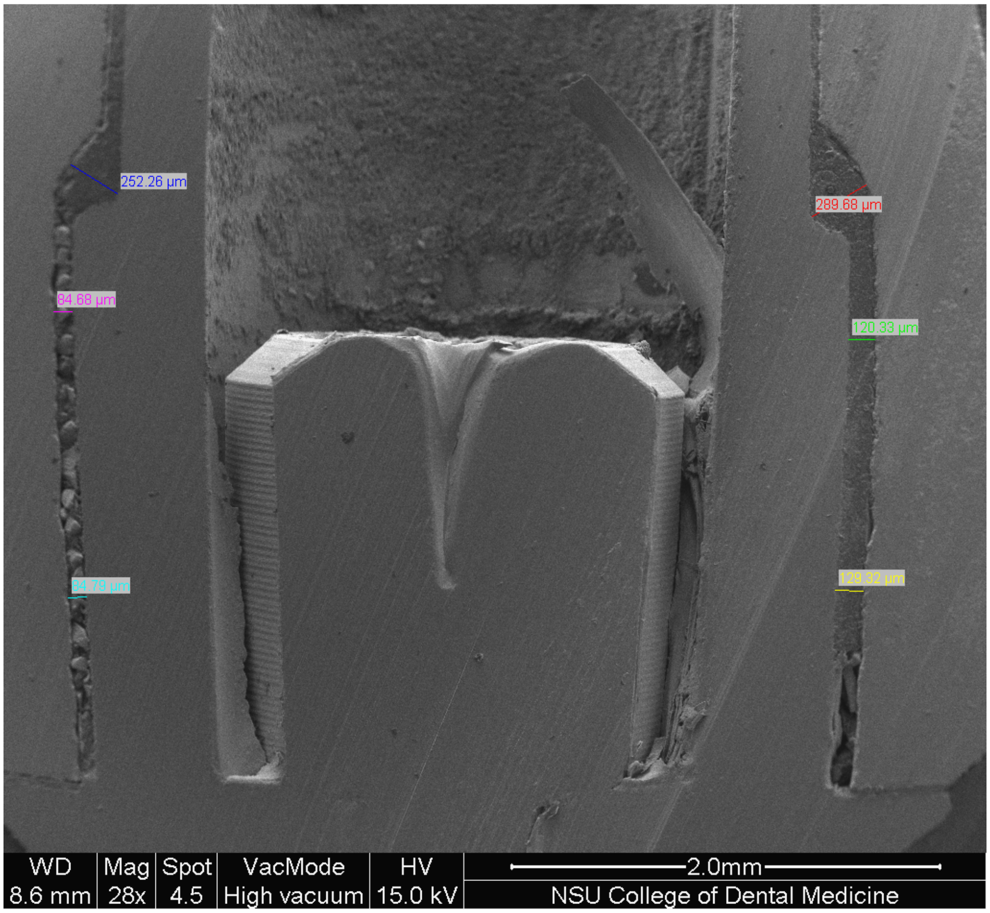


Figure 34: Three points of measurement for modified zirconia abutments.

The mean values of the microgap (Table 3) in point A were 180.11 microns for the control group, 182.09 microns for Group 1, 187.54 microns for Group 2 and 256.97 microns for Group 3. The mean values of the microgap in point B were 52.62 microns for the control group, 68.88 microns for Group 1, 69.43 microns for Group 2 and 117.73 microns for Group 3. The mean values of the microgap in point C were 55.07 microns for the control group, 72.35 microns for Group 1, 59.35 microns for Group 2 and 109.54 microns for Group 3.

Microgap (in microns)	Control	Group 1	Group 2	Group 3
Point A mean	180.11	182.09	187.54	256.97
Point A St deviation	11.5	21.84	16.56	6.66
Point B mean	52.62	68.88	69.43	117.73
Point B St deviation	18.49	15.98	13.01	46.73
Point C mean	55.07	72.35	59.35	109.54
Point C St deviation	7.62	27.92	15.69	35

Table 3: Mean values of the microgap between zirconia component and titanium insert.

Bonferroni test was performed, and statistically significant differences were found at point A between the control group and Group 3, as well as between Group 1 and Group 3 ($P<0.05$). This is the first study that evaluated this comparison, and shows that maybe the coronal region is the weak point of the cementation between the zirconia component and titanium insert. Regarding points B and C, no statistically significant differences were found (Fig.35).

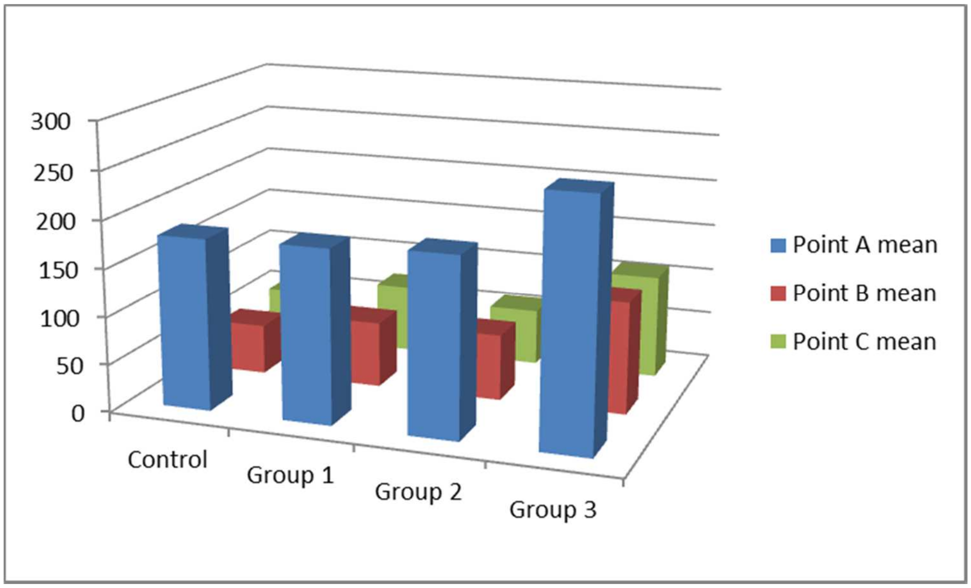


Figure 35: Mean values of the microgap between zirconia component and titanium insert.

Chapter 4: Discussion

4.1 Interface between implant and abutment

Placement of maxillary anterior implant restorations can be one of the most challenging dental procedures. In addition to the biological challenges related to implant placement, bone loss or papilla height, there are multiple prosthetic issues that need to be addressed. The esthetic result of the restoration can be influenced by the type of abutment used. As stated above, titanium has been the material of choice for a long time because of mechanical properties, until advanced esthetic demands shifted the paradigm to more tooth-color abutments made from ceramic materials. In the beginning, multiple alternatives to titanium were proposed like the gold (Fig.36) or pink hued titanium abutments. They can still be used depending on the case, but zirconia has become very popular among clinicians because of its hardness, which provides a long term result in the demanding oral environment.

Figure 36: Gold hue titanium abutment.

Multiple methods have been used to measure the precision of fit of implant restorations. Jemt et al reported methods based on stylus contact techniques and photogrammetric methods[44], while Lang used a radiographic method to assess fit.[45] The methodology employed in the present study gave the opportunity to quantify the microgap between implant and abutment. The quantitative measurements were made using SEM images. Three different intervals were used in this study to evaluate if the microgap is increased throughout a fatigue process. Previous studies have shown increased wear in the interface between implant and abutment because of the difference in roughness and coefficient of friction between the two mating surfaces.[37] Actually, it was shown in a pilot study that titanium can be transferred to a zirconia abutment and disrupt the internal connection of the implant fixture. On the other hand, Baixe et al reported smaller microgaps for four systems of zirconia abutments compared to those described in the literature for titanium abutments.[32] In addition to these results regarding wear, there have been studies in the literature that show that a zirconia abutment fracture occurs usually at the interface with the implant and can lead to catastrophic failure of the whole restoration (Fig.37).

Figure 37: Fractured zirconia abutment.

This led to the release in the market of modified zirconia abutments which combine the esthetic advantage of having a whitish color and the mechanical advantage of having similar materials in this critical location.

Another factor that could influence the microgap between implant and abutment is the fabricating method. The most commonly used method of milling abutments is CAD/CAM technology. The present study used customized CAD/CAM modified zirconia and titanium abutments of the same configuration made by NobelProcera (Nobel Biocare, Switzerland). The results of the study showed no statistically significant difference between the two types of abutments. This makes CAD/CAM modified zirconia abutments a viable option from both esthetic and mechanical standpoints. Cyclic loading up to 500,000 cycles did not seem to influence the connection of the implant and the abutment. The titanium-to-titanium interface of these type of abutments is a big benefit. Brodbeck described wear of the external hex of an implant loaded with an all-ceramic alumina abutment when micromovement occurred because of abutment screw loosening.[46] Under 35x magnification, he showed wear on the implant loaded via ceramic abutments. The corners of the hex were rounded and the top of the hex had altered to a ring shape. Klotz et al[37] was one of the first to quantify the difference of wear, and found that zirconia abutments could cause almost 10 times greater wear. However, the clinical implications of this difference are still unknown.

The present study compared the microgap at 5 points and showed that most of the stresses are concentrated towards the coronal part of the interface. The same can be confirmed by finite element analysis, as shown in a study recently published by Alvarez et al.[47] They showed that during axial loading, the abutment receives the most stresses in a well delineated area close to its margin (Fig.38). They also mentioned that implants with platform switching, like the one that was used in our pilot study, have a more favorable stress distribution and that the stresses on the abutment and the screw gradually increase as the load become more off axis.

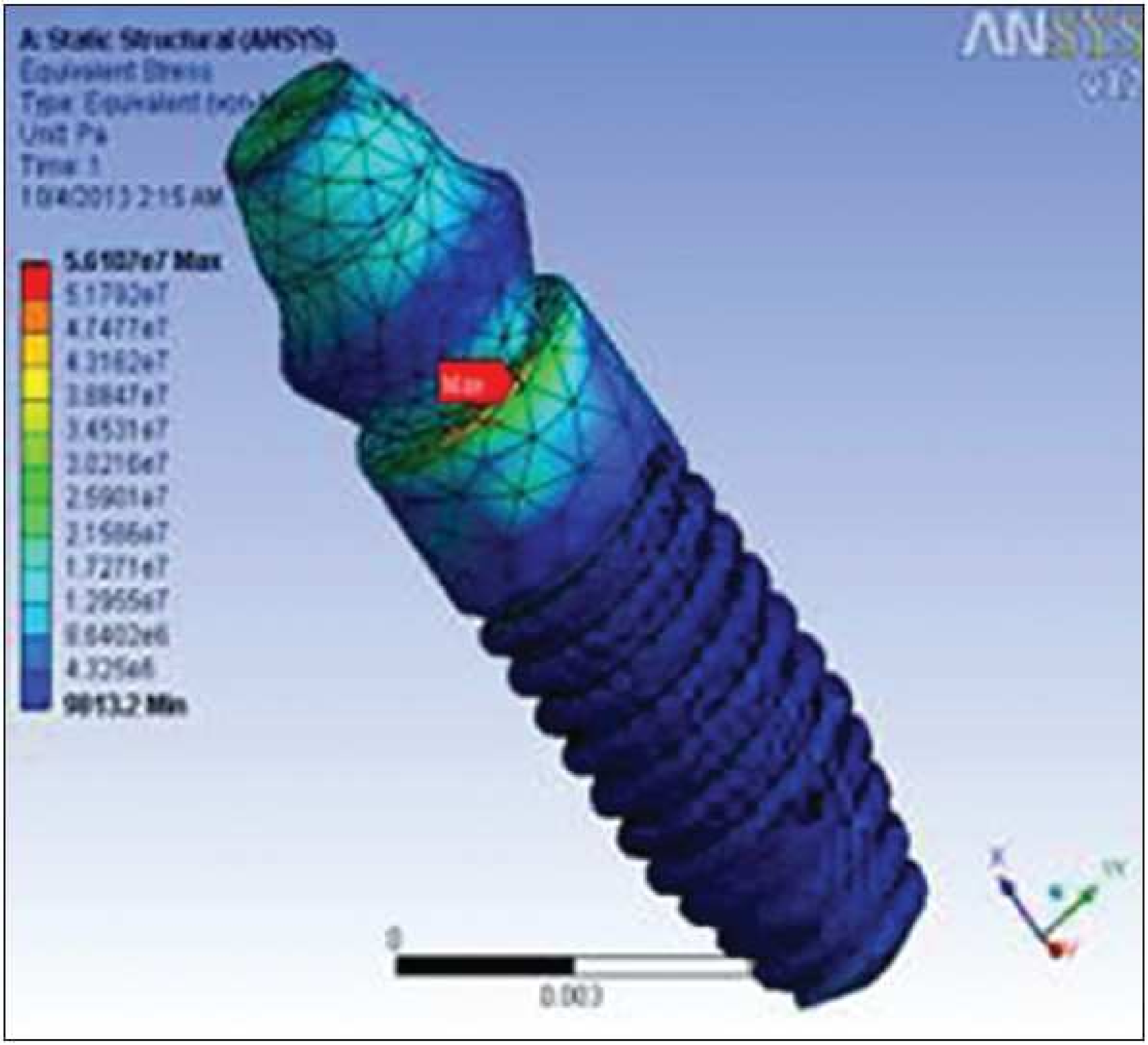


Figure 38: Stress distribution point (FEA).

4.2 Fractured specimen- Screw design

In the present pilot study a force of 100 N was applied at frequency of 1,25 Hz in order to perform the fatigue loading test. This number came as an average of the masticatory forces in the anterior region that vary between 50 and 150 N.[48,49] This force is almost three times bigger when posterior teeth are to be considered.

One of the most impressive findings of this study was the fractured titanium specimen. We can assume that the screw failed first, which caused the abutment to become mobile and fracture at a later stage, not being able to withstand the applied off axis force. This shows the paramount importance of a small screw in the survival of the whole prosthesis. The screws used in the present study were made of titanium. Some companies (i.e. Biomet 3i, Palm Beach Gardens, Florida) use gold screws with their components. This study did not measure the qualitative screw deformation, but it can be argued that the screw from the fractured specimen was totally stripped.

The stability of implant-abutment connection is influenced by factors, such as screw head design, screw geometry, material, as well the level of preload.[50] Each screw acts as a spring and preload is the initial clamping force that keeps the two components together (Fig.39). As a screw is tightened, it elongates, thereby producing tension. Elastic recovery of the screw pulls the two parts together, creating this clamping force.[51] Adequate preload creates less micromotion of the interface between implant and abutment and less screw loosening.[51,52]

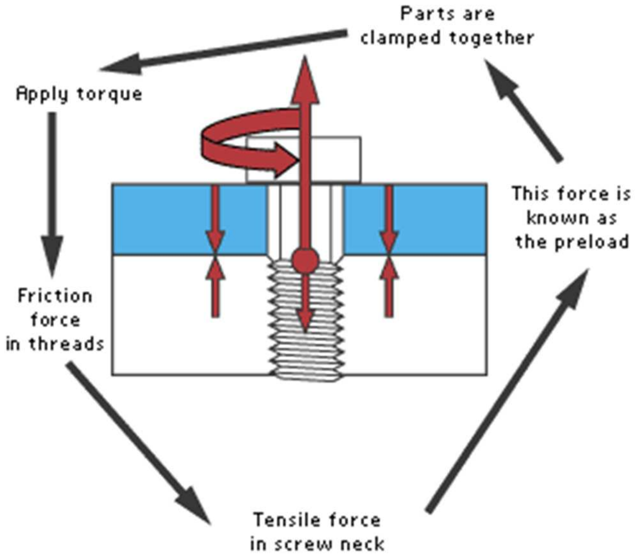


Figure 39: Preload mechanism.

Initial preload is very important because occlusal forces will eventually change the clamping force that keeps the implant components together. Too little preload might result in screw loosening.[53] To maximize the preload and minimize the loss of input torque to friction, the head of the screw should be wider than the thread diameter. A flat head screw distributes forces more evenly within the threads and is less likely to distort a non passive casting. As such, the abutment head should also be flat on top to increase the clamping force in the screw head and the tensile force in the threads.[54]

In terms of material, the most commonly used screws are made from gold or titanium. Gold screws are designed to be more flexible due to higher modulus of elasticity.[55] Implant restorations retained with gold or gold coated screws show a reduction of screw loosening and increased clamping force compared to titanium ones.[56,57] Titanium screws are stronger than gold ones, but due to lower modulus of elasticity are more prone to deform and eventually fracture. Another disadvantage reported in the literature for titanium retaining screws is the galling phenomenon, which causes excessive friction of the two mating surfaces. Titanium of the retaining screw slides in contact with the titanium of the implant body and molecules transfer from the mating surfaces.[58] This has been described as adhesive wear mechanism and can cause slight deformation to both the implant and the screw.[59] As far as the screw diameter is concerned, the greater the diameter, the higher the preload that may be applied.[50]

In the present pilot study, we assume that the preload was similar for all samples because we followed the manufacturer recommendations for torque values (25 Ncm). Since the screws were all made from the same material and the same design, they should have similar initial clamping force. The question that arises is why one of the 16 specimens showed screw loosening, which under the continuous applied force resulted in a fractured abutment screw. Possible minute flaw in the fabrication process of the screw might be an answer, but clinicians can neither predict nor evaluate that in everyday practice. What would be more useful to elaborate on, is what kind of preventive management could somebody employ in order to minimize the risk for screw loosening of the implant restorations.

Multiple preventive measurements have been proposed in the literature. They can be summarized in the following:[50]

1. It is recommended in clinical practice to retorque the implant screws approximately 10 min after the initial torque, in order to reduce the settling effect.[53,60,61] This will maximize the initial preload of the screws.
2. External hex implant systems have been proven more prone to screw loosening;[12] for that most of the implant companies have switched to an internal connection type of implant.
3. Mechanical torque gauges should be used instead of hand drivers to ensure a consistent torque value.[62]
4. Frameworks should have minimal cantilevers and single tooth restorations should comprise of components with anti-rotational features and low tolerance levels for misfit.[63]

4.3 Interface between zirconia component and titanium insert

As mentioned before, this modified abutment combines esthetic and mechanical advantages of both titanium and zirconia. There are two types of fabrication for these types of abutments. The zirconia component can be attached to the titanium insert either by friction fit or by bonding. Usually, a resin cement is preferable after treating the components with air abrasion, HFl acid etching and a bonding agent. Recently, Kim et al compared the maximum load capacity of three different types of internal connection zirconia abutments.[64] They used three groups of abutments: the first made from zirconia, the second from zirconia component attached to the metal insert through friction fit and the third was made from zirconia component bonded to the metal insert. They concluded that the latter displayed a statistically higher maximum load capacity compared to the other groups.[64] This study has been one of the very few that evaluates the load capacity of implant abutments as well as their mode of failure. It is noteworthy, however, to mention that the authors investigated the samples under static load only.

Static may only be one type of force among many that can be applied to the abutment-coping complex. Thus different results may be demonstrated when fatigue loading is applied. Nevertheless, to design a fatigue loading test, static loading is essential to provide a starting point and calculate the force that will be applied in the implant-abutment complex.[64]

Our present pilot study is, to the author's knowledge the first one that compares the microgap in the interface between the zirconia component and the titanium insert for CAD/CAM fabricated abutments (Fig.40). The results showed that the microgap for Group 3 in the coronal part of the interface is greater than the control group. In other words, there was a statistically significant difference after fatigue loading the specimens for 500,000 cycles compared to the non loaded ones.

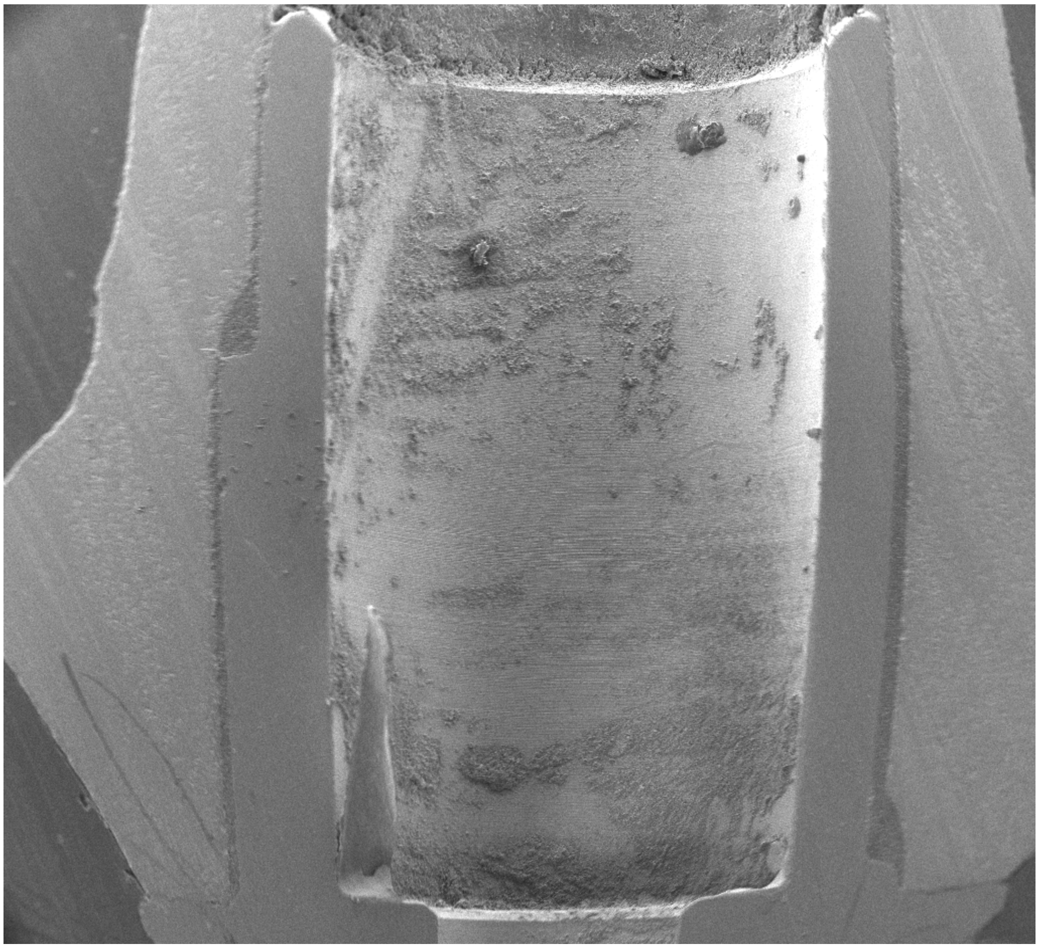


Figure 40: Microgap between zirconia and titanium insert (control group).

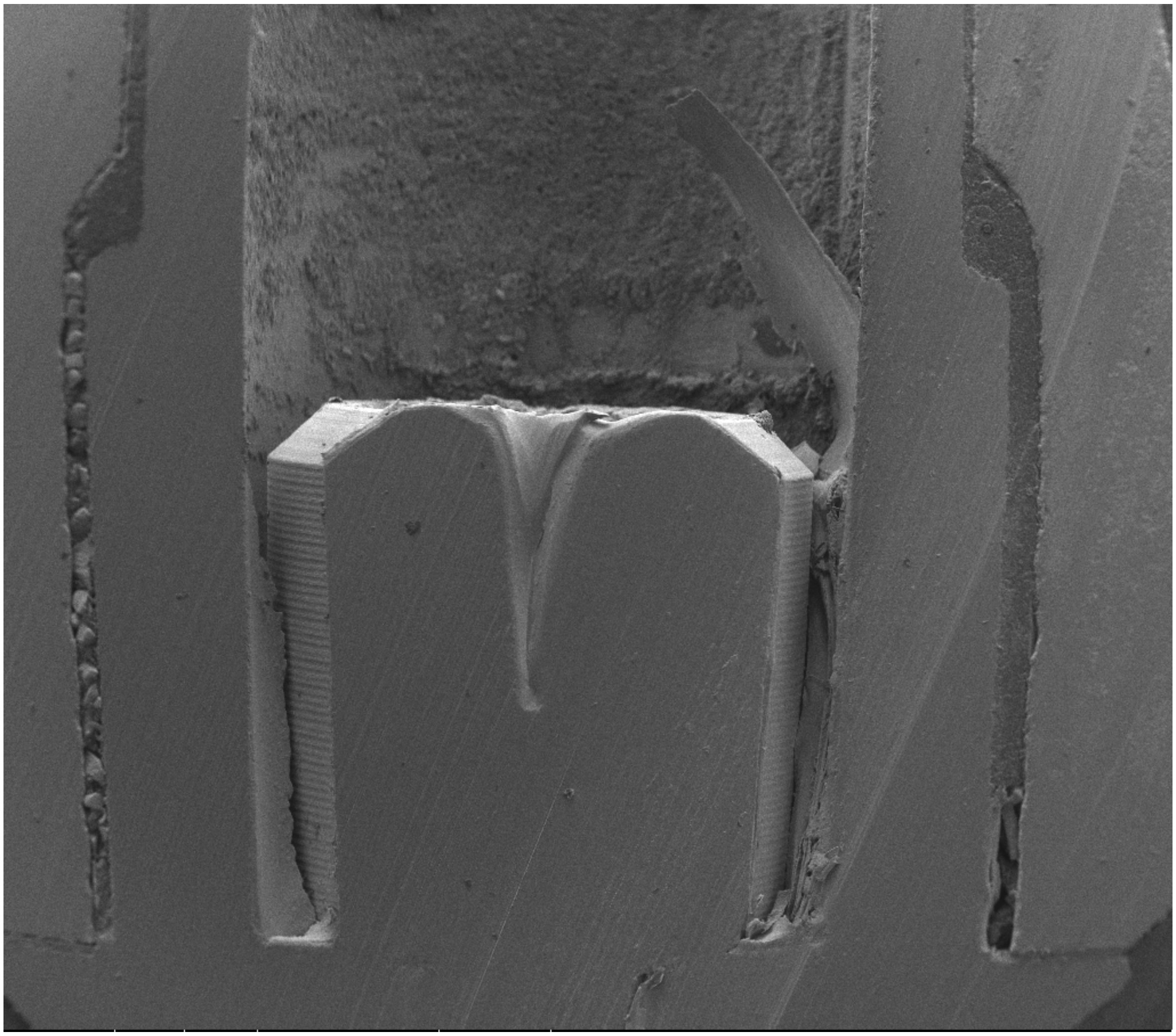


Figure 41: Microgap between zirconia and titanium insert (Group 3).

In Figures 40 and 41, it can be appreciated that there are differences in the microgap between the zirconia component and the titanium insert under 28x magnification in the SEM. In Figure 41, it is obvious that some particles have filled the space between the titanium insert and the zirconia material. It is not known if those are small disintegrated cement particles that look like this under magnification, or debris particles created by the sectioning process, despite the fact that it was done in an aqueous environment and that all the specimens were steam cleaned before the SEM image analysis. If they are cement particles, it means that after 500,000 cycles of fatigue loading the cement had begun to break down and the microgap increased. No visible detachment or mobility of the components was found after 500,000 cycles of loading. However, it would be interesting to continue the loading process up to 1,000,000 cycles or even more and reevaluate the microgap under the same magnification. It is needless to mention that in case that the cement breaks down, the two components are detached and the whole prosthesis can be jeopardized with catastrophic failure.

As far as quantifying the microgap is concerned, in the randomly selected point A, that represents the most coronal part of the interface, the control group had a mean microgap of 180.11 microns and the samples that were loaded for 500,000 cycles presented with mean microgap of 256.97 microns. This difference was statistically significant at the 95% confidence interval. In the middle part of the interface the mean microgap for the control group was 52.62 microns and 117.73 microns for Group 3. In Point C that represents the most apical part of the interface evaluated the respective mean values were 55.07 microns for the control group and 109.54 for Group 3. Even though the values were doubled after cyclic loading, no statistical differences were found for points B or C at 0.05 level. Future research should be conducted to evaluate the interface between the titanium insert and the bonded zirconia component for modified abutments. If similar results confirm our findings, the dental clinician should shift to different types of abutments. Indeed, recently Protopapadaki et al,[65] compared the resistance of modified zirconia abutment with a pressable metal ceramic custom abutment that had not been used before. The experimental group consisted of a metal substructure casted with a high noble ceramic alloy, called Lodestar (Ivoclar Vivadent, Amherst, NY). Two layers of opaque were applied on the metal and then leucite glass ceramic was pressed on the abutments to give a whitish appearance. Even if the leucite glass ceramic is considered a material with compromised mechanical properties, they found that under static loading the mean load to failure was significantly higher for the tested group compared to the modified zirconia abutments.[65] This type of pressable custom abutments on metal substructure could be also a viable esthetic option for the clinician if more studies confirm the above mentioned results.

4.4 Limitations of the study

Several limitations can be identified in this pilot study. To begin with, the sample size can be characterized as small due to the limited available budget. That gives less validity to our results. Especially since one of the CAD/CAM titanium abutments fractured during the loading process we had only one sample for Group 3. Similar studies in the literature have used at least five implant abutment assemblies.[24,32,36]

Another limitation of the study is related to the location as well as the type of the applied load. The anterior part of the piston used for fatigue testing was positioned approximately 1 mm below the incisal edge of the abutments. This model resembles a class I dentition. However, in cases of class II dentition, where the load is applied more cervically, or class III, where the load is applied more incisally, the force distribution will be different and the fracture mode and load may also be different. Furthermore, we know that in clinical situations, the anterior teeth share the load between them, meaning that the load applied during mastication is shared between central and lateral incisors as well as canines. This cannot be measured in a study model like ours. As far as type of applied force is concerned, the fatigue loading that was used in this pilot study resembles the masticatory process of the patients. A more clinically relevant approach would be to apply a static load on the samples that resembles the parafunctional habits of patients, like clenching or bruxing. These habits are known to produce greater forces to the implant restorations with more negative impact both from a biologic and prosthetic standpoint.

In addition to this, it should be mentioned that the mounting method used for the loading can play a significant role in the results. Silva et al[66] related the effect of load forces with two different mounting media. They concluded that mounting in bone simulating foam blocks resulted predominately in dislodgement of the complex from the block. This problem was overcome by using super glue and autopolymerising ortho resin to secure the specimens during the loading process. There has not been a universally accepted mounting technique that can accurately resemble the clinical scenario of the implant being integrated in the bone.

Another important limitation of this study might be the sectioning procedure. It was performed in aqueous environment by precision saw that was sharpened every 2 samples. The water was used to keep the temperature relatively low so there is no melting of the resin that kept the samples secure. After the process the samples were steam cleaned and coated with a gold powder that would accommodate the image analysis. The problem with this technique is that debris or metal particles caused by cutting the specimens might "close the microgaps". Looking in the literature for an alternative to this technique, the use of 3D micro Computer Tomography should be mentioned. Stimmelmayr et al[35] comparing the wear of titanium implants when connected to titanium and one-piece zirconia abutments mounted in resin blocks, used reference marks and superimposed the micro computer micrographs before and after cyclic loading. In this way, it was not necessary to section the specimens lengthwise to measure the microgap.

Going further in evaluating our study, it is noticeable that there were no crowns cemented on top of the abutments before cyclic loading. This means that the pistons applied the force directly on the incisal edge of the CAD/CAM abutments. We know that in clinical practice this is not the case, because there is a cement retained restoration that first receives the applied force and then transmits it to the abutment. The material which is used for fabrication of the restoration, as well as the cement that is used, could provide a totally different interface that could change the results of the present study.

Probably the most important limitation of this study was the fact that the cyclic loading occurred at room temperature without the presence of a liquid, that would better resemble the oral environment. The oral cavity is one of the most challenging environments for biomaterial interaction. More specifically, recent literature has mentioned the degradation of the mechanical properties of Y-TZP zirconia in the presence of saliva.[67] This phenomenon is called low temperature degradation (LTD). It is known by now that the sintering process of zirconia polycrystals can influence low temperature degradation. Inokoshi et al[68] compared three different sintering temperatures and found that specimens sintered at 1450^0 Celsius for 1 h result in a smaller grain size and better mechanical properties with the best resistance to LTD. Future research should be conducted to evaluate the behavior of modified zirconia abutments in the presence of saliva.

Last but not least, it should be mentioned that the present pilot study evaluated the microgap changes in the interface between implant and abutment up to 500,000 cycles. This number corresponds to almost one year of masticatory loading. In clinical practice, an implant supported restoration should give the patient five to seven years of function, free of complications in order to be considered successful. In their studies, Koltz et al[37] and Stimmelmayr et al[35] loaded their specimens for 1 and 1.2 million cycles respectively. There has not been a number of cycles proposed as the baseline for future studies, but it can be said that several million cycles will be needed to evaluate the long term behavior for CAD/ CAM titanium and modified zirconia abutments.

Chapter 5: Conclusions

Within the limitations of the present pilot study the following conclusions can be drawn:

1. No statistical difference was found in the interface between implants and CAD/CAM titanium and modified zirconia abutments up to 500,000 cycles.
2. There was a statistically significant difference in the microgap of the interface between zirconia component and titanium insert for the CAD/CAM modified zirconia abutments. Further research should evaluate this critical interface since there is not available published literature.
3. If there is a flaw in the fabrication process of the screw that retains the abutment, the long term survival of the whole prosthesis can be jeopardized.

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