An In Vitro Pilot Study Compared Volumetric Changes of Dental Implants in the Titanium Abutment and Zirconia Abutment, after Cyclic Loading

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Abstract

Although dental implants have a high success rate, aesthetic effects are a concern. Zirconia abutments are used to prevent tissue shadowing from titanium; nevertheless, the literature suggests that using zirconia abutments leads to increased degradation of the implant interface, which could lead to biological problems such as Titanium scars and poisonous metals. Previous research has looked at the mechanical features of the implant/abutment connection, but it hasn't considered the volume loss of the dental implant that occurs in the oral cavity's dynamic environment. The volume loss of wear at the dental implant under cyclic loading was studied in this pilot investigation. The goal of this pilot study was to determine the volume of titanium implants after cyclic loading in 2 main types of abutments. In the investigation, fourteen dental implants were used. 7 dental implants were used in conjunction with titanium abutments (Group1: Variobase abutment Straumann) and another 7 dental implants with zirconia abutments (Group 2: CARE abutment Straumann). Cyclic loading was applied to the abutments (1×10^6 cycles, axial load, 100N, 15 Hz). The volumetric of the titanium implant was evaluated using a real density analyzer (AccuPyc II). The independent *t*-test was used to investigate differences in implant volume and % volume loss among two abutment types. A *p*-value of less than 0.05 was considered statistically significant. After cyclic loading, the volume of dental implants in the zirconia group decreased and the photograph loading found the grayish area was found at the hex of the dental abutment. After cyclic loading, there was no significant difference in the volumetric changes of dental implants in the titanium abutment and zirconia abutment. Cyclic loading at 100 N causes titanium implants to lose more volume when connected to zirconia abutments than when connected to titanium abutments.

Keywords: *dental implant, dental abutment, zirconia, titanium, gas pycnometer*

1. Introduction

Requirements for the success of anterior dental implants include biological components and esthetic results. Through thin gingival tissue, the traditional and extensively used titanium abutment reveals an unfavorable metal color. Zirconia abutment has become a study focus in recent years due to its ideal aesthetic impression and good biological and mechanical performance (Lia, Loredana, Antonio, & Paola, 2002). The gray tone of titanium, on the other hand, may cause esthetic problems. In some cases, soft tissue height above the implant level may be insufficient when the definitive restoration is completed or after marginal peri-implant bone loss and soft tissue recession. The display of metal components may be unattractive.

Zirconia, like titanium, is a biocompatible substance that benefits the soft tissues that surround it. Radiopaque zirconia, which means it can be seen on radiographs. It has an ivory hue that is identical to natural teeth. This feature is highly important for implant esthetics, it permits light to penetrate through the vital contacts between the marginal gingival tissue and the prosthetic components, which is especially important in patients with prominent lip lines. (Aras & Modgi, 2012).

Zirconia has good mechanical qualities including flexural strength and fracture toughness (Zadeh et al., 2018). Additionally, a brief clinical investigation found that zirconia has acceptable biological, esthetic, and mechanical qualities and that it may be employed in a variety of prosthetic applications on the teeth or in implants (Hanawa, 2020). According to a recent study, when a one-piece zirconia abutment and a titanium implant are subjected to simulated mastication, wear occurs at the implant-abutment interface. Due to the titanium implant's transfer to the zirconia abutment, it wears both macroscopically and microscopically. After loading, the zirconia abutment develops a grey banding appearance that wraps completely around the abutment (Klotz, 2009). Close contact between the abutment and the implant is critical for the implant, abutment, and prosthesis to be strong and stable. This issue might result in screw loosening and abutment fracture at the connector. (Watanabe et al., 2022).

According to Boyle's law, Mariotte's pressure is inversely proportional to volume, which means that as volume drops, the gas's pressure increases proportionately. As a result, a gas pycnometer was developed to determine the density or volume of granular, porous, or liquid substances, as well as the density of their mixtures (e.g., rocks, coal, pigments, ceramic, drugs, seeds). There are three types of gas pycnometers described in the literature: "constant-volume," "variable-volume," and "comparative." The constant-volume pycnometer is commonly used because, unlike the variable-volume pycnometer, it does not require a properly calibrated pressure transducer and is comparatively easy to create in comparison to the comparative pycnometer. (Tamari, & Aguilar- Chávez, 2005). On that account, the constant-volume pycnometer was selected for investigation in this pilot project.

Only one pilot study (José, 2017) used scanning electron microscopy to assess wear at the titanium–zirconia implant–abutment contact. Regrettably, the quantity of wear was not examined. As a result, this was the knowledge gap for measuring the volume loss of the dental implants when connected to different abutment materials.

2. Objective

This study aims to compare the volumetric changes of the dental titanium implant to two different abutment materials after cyclic load.

3. Materials and methods

Fourteen bone level implants with a dimension of 4.1 mm. and a length of 10 mm. (The Straumann® Bone Level Implant) were separated into two groups. The Variobase abutments were connected in Group 1. Another seven implants were fitted with zirconia abutments in Group 2. All specimens were loaded into a loading jig, which kept them in place in the testing base. The loading jig and specimen were placed on the compressive machine's loading platform (Universal testing machine, Instron) The loading base had a steep slope of 30 degrees above the horizontal plane. This tilt was utilized to model how forces operate on an implant by performing off-axis loading. In a Universal Testing Machine, the specimens were loaded with cyclically loaded forces with 1x 10^6 cycles at frequencies of 15 Hz, 100 N according to ISO DIN 14801:2016 (previously known as ISO 14801:2007) (Dannan, 2017) requirements. To simulate occlusal force and movement over 5 years, each specimen was subjected to 1 million load cycles in total. The specimens were then removed from the base once the loading test was finished. The samples were removed from the testing base after cyclic loading, and the abutment was unscrewed from the implant. Before the abutment was installed on the platform, the implant volume (cm^3) was measured. The volumetric of dental implants was measured using a True Density Analyzer (AccuPyc II) After the mechanical cycle, the same analysis technique was employed to determine the implant volume.

3.1 Statistical Analysis

The Shapiro-Wilk analysis was performed to determine the data's normal distribution. The uniformity of variances was determined using Levene's test. The independent t-test was performed to compare the percent volume loss of two different abutment types. The statistical analysis was performed using SPSS Statistics for Windows, version 22.0 (IBM, Armonk, NY, USA), and a p-value of less than 0.05 was considered statistically significant.

7 Titanium implants

The specimens were analyzing the Preload volume by Gas pycnometry

1. Specimens were placed in resin blocks.
2. Inserted the abutment of each group in specimen

Group1. Titanium abutment

Group2. Zirconia abutment

Cyclic load (Universal testing machine)

Gas pycnometry was used to determine the post-load volume of the specimens.

Figure 1 Diagram of method

Table 1 Mean (Standard Deviation) of preload volumes, post-load volumes, and percent volume loss according to the three different abutment types

Group (N=7 /Group)	Mean ± SD (Preload volume /cm^3)	Mean ± SD (Post-load volume /cm^3)	Mean ± SD (volume loss /cm^3)	Mean ± SD (% volume loss)
1. Dental implant/Titanium abutment	0.16±0.03	0.14±0.03	0.02±0.02	11.45±11.91
2.Dental implant/Zirconia Abutment	0.17±0.01	0.14±0.02	0.03±0.01	17.42±8.31
p value [a]	0.627	0.696	0.304	0.299

[a] Differences were analyzed using an independent test

Figure 2 Zirconia abutment and Titanium after cyclic loading

4. Results and Discussion

The results of the independent *t*-test comparing volumetric dental implants at the various abutment types are displayed in table 1. The volume reduction of the dental implant in all groups were shown in table 1. Pre-load volume of dental implants between the two groups found no statistically significant difference (p=0.493). For the post-load volume of dental implants, the Titanium group showed a slightly higher volume (0.14±0.03) than the Zirconia group (0.14±0.16). In contrast, the percent volume loss of the Zirconia group indicated a higher volume (17.42±8.31) than those in the Titanium group (11.45±11.91). Unfortunately, there was no statistically significant difference in post-load volume (p=0.671) or percent volume load (p=0.235) between the two groups. After the cyclic loading zirconia abutments revealed some particles of titanium at the connection as shown in figure 3. Because the sample's preload value was little, when converted to a %, the outcome was a large figure. Additionally, because the sample size was small, the SD was relatively large.

This pilot study compared the volumetric change of dental implants after being connected with titanium and zirconia abutments. Because the percentage of volumetric loss of a dental implant connected to a zirconia abutment was similar to that connected to a titanium abutment following cyclic loading.

Although the results showed that the dental implant in the zirconia group slightly lost more volume than the titanium group and earlier studies have demonstrated that this is not contra-indication in esthetic cases. The zirconia abutment should be strong enough to support a heavy occlusal load. By using a computer-controlled universal testing instrument at 30 degrees from the vertical axis of the specimens, Kim et al. (Kim et al., 2009) discovered that the fracture load of zirconia abutment was 480 N. At the cervix of the tooth, eight specimen fractures were seen. However, Gehrke et al (2006) demonstrated a drop-in zirconia strength from 672 N without cyclic loading to less than 405 N following cyclic loading. When compared to Yildirim et al (2003). (Gehrke et al., 2016; Yildirim, Fischer, Marx, & Edelhoff, 2003), the results' of thermos mechanical fatigue tests on zirconia at stresses less than 50 N over a period of 1,200,000 cycles demonstrated a decrease in strength (between 457 and 281 N).

Implant alloys were significantly less damaged when zirconia abutment materials were used. In fact, when compared to titanium attack, Zirconia groupings resulted in a five- to six-fold reduction in wear and discharge of metal particles from implant alloys. Zirconia abutments have been found in clinical trials to have a lower rate of degradation at the implant/abutment interface, possibly resulting in much less metal transfer, less tissue destruction and pigmentation, and improved long-term outcomes. (Sikora et al., 2018).

The current in vivo investigation determined the mode of failure for zirconia and titanium abutments. The most common mode of failure for zirconia was screw deformation, whereas the most common mode of failure for titanium abutments was deformation of the assembly component, either the abutment or the analog.(Alqahtani & AlAmar, 2020). Several previous studies demonstrated that stress distribution to the cortical bone was nearly identical in various types of abutments. The higher modulus of elasticity of the zirconia abutment (MOE). MOE is a critical parameter that has a significant effect on how materials behave. Zirconia abutments have a higher MOE (200 GPa) than titanium abutments (110 GPa), and it was discovered that abutments may simply act as a conduit for forces to be transferred to the bone, with the different abutment types having no effect on it (Hamedirad et al., 2018).

Cook et al. (1999) utilized a noncontact approach called a gas displacement pycnometer to determine the volume changes in composite materials during polymerization in the dry state 1999. This procedure is not time intensive because it just determines the final amount of shrinkage. (Cook, Forrest, & Goodwin, 1999)

Porosity is a critical physical property of materials used in packing, shipping, storing, and drying processes. Additionally, it is a critical technical parameter in the design of engineering systems, the evaluation of equipment processes, and product analysis. Pycnometry is a technique used to determine the volumetric and thus density of particulate, spongy, and/or liquid materials such as stones, soils, anthracite, dyes, ceramics, minerals, pharmaceuticals, thin films, polythene, dentition, cacao, seeds, bugs, or even live animals. (Mai, & Wang, 2020).

The fatigue loading methodology utilized in this study (at a 30-degree angle, 100 N) is a requirement for all implants to obtain certification. This involves unilateral loading of implants bound to a brass cylinder, which is not a realistic scenario; multi-directional varying pressures, and also embedding the implants in a material having a similar elastic modulus to the bone, would be more realistic. Statistical analysis could not be done since just two implants of each design were used in this pilot trial. Further exploration with bigger sample size and the application of multidirectional loads is encouraged to investigate findings in a more in vivo medical context. When using ISO standard 14801:2003, This study's data shed light on the function of cylindrical implant-abutment relations.

These findings corroborate prior research indicating that titanium implants exhibit more abrasion on the interface during loops stress when attached to zirconia abutments than when connected to titanium abutments. The clinical significance, however, remained unclear, as disruption to the inside implant interface could result in the failure of the prosthesis. Even though pilot testing has limitations due to the difficulties of mimicking all clinical variables, the small sample size, the use of cyclic loading without saliva throughout testing, and the use of only the dimensions of maxillary central incisors. The volumetric change measured by a gas pycnometer should be calibrated with other techniques to reveal the dimensions and location of the worn area for a precise result.

5. Conclusion

The implants with zirconia abutments showed the same rate of loss and wear as the implants with titanium abutments after cyclic loading. After a series of loading cycles, the amount of titanium transfer on the zirconia abutment increased slightly. The clinical consequences of this discovery are unknown at this time; however, the risk of component loosening and eventual fracture, as well as the release of particle titanium debris, could be cause for concern.

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7. References

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