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Investigation of the Fracture Strength Between Dental Implant and Ti-Base Abutment Produced with Different Heights and Grades of Titanium Material

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Research Article

History

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ABSTRACT

New prosthetic designs have been developed in order to provide a balanced transmission of the stress caused by the chewing function to other mechanical and anatomical structures and these designs have revealed new research areas. An example of this is screw-retained implant-supported prostheses. With screw-retained prostheses, the residual cement problem is eliminated. However, abutment material and abutment design may adversely affect the mechanical and aesthetic properties of prostheses. Ti-base abutments have been developed to solve these problems. However, studies on clinical success, material content and abutment height of ti-base abutments remain up-to-date. In our study, the effect or abutment heights on the bond strength and stress distribution with monolithic zirconia crowns in ti-base abutments manufactured from different titanium Gr types will be tested. Titanium Gr 4, Gr 5 and Gr 23 ELI materials will be used in our study. A total of 7 groups are planned with ti-base abutments with an abutment length of 3.5 mm, 5.5 mm for Gr 4 and Gr 5, abutment length of 3.5 mm, 5.5 mm and 7 mm for Gr 23. In the in vitro experiment, the fracture strength of the samples will be tested with the universal testing device. total of 77 implants, ti-base abutments and monolithic zirconia crowns will be used by creating 11 samples for each study group. The obtained values will be recorded in Newtons and Megapascals. The data will be analyzed using the SPSS 22.0 program. As a result, while the lowest fracture strength values were observed in Gr 4 Ti material in all ti-base abutment lengths in the samples for which the fracture strength test was performed, similar values were observed in the ti-base abutments produced from Gr 5 and Gr 23 ELI alloys. When the relationship of bonding strengths with Ti alloys was evaluated, it was seen that there was no significant difference between Ti alloys.

Keywords: Grade 4, Grade 5, Grade 23, Fracture Strength.

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Introduction

The planning of implant-supported prostheses may vary as removable or fixed prostheses according to the width of the edentulous area and the condition of hard and soft tissues in the mouth.[1] According to these plans, the number of implants applied, and the type of material changed. This change has brought along new problems. One of the main problems encountered in oral implantology is mechanical complications in prosthesis structures. The stress on the restoration, abutment and implant structures due to the chewing function is the main factor of mechanical complications. Today, many materials and production techniques are being investigated to better meet this stress and ensure it is transmitted to other mechanical and anatomical structures within biological limits.

Today, the most common material type in dental implant production is titanium and titanium alloys.[2] Compared to other implant materials, the modulus of elasticity of titanium is closer to the modulus of elasticity of bone. Thus, the force distribution at the bone-implant interface is more balanced.[3] Its compatibility with biological tissues, exceptionally good corrosion resistance, low cost and high material resistance have made titanium a more preferred material.[4-6]

One of the important components of implant supported prostheses is abutments. Titanium, alumina, and zirconia were used as material types in abutments. Alumina gives a radiolucent appearance with insufficient mechanical resistance.

The design combining the mechanical properties of titanium abutments with the aesthetic properties of zirconia abutments is called 'Hybrid Abutment'.[7,8] Since the mechanical properties of hybrid abutments are higher than those of one-piece zirconia abutments, titanium abutments called 'Ti-base' have started to be produced. However, the mechanical properties of ti-base abutments and their physical interaction with crown materials have not been sufficiently elucidated.

The aim of this study is to investigate the effect of different chimney heights on fracture strength, connection strength and stress distribution in ti-base abutments made of different titanium types.

One of the other aims of the study is to elucidate the mechanical properties of titanium Gr 23 ELI alloy in the implant system with ti-base by comparing it with other titanium types.

Hypotheses of this study;

The fracture strength values of the ti-base abutment-implant system produced from Gr 23 ELI titanium will be lower than the fracture strength values of the ti-base abutment-implant systems produced with other titanium types.

The change in the height of the Ti-base chimney will not affect the bond strength values of monolithic zirconia crowns.

Materials and Methods

This study was carried out under in vitro conditions in Sivas Cumhuriyet University Faculty of Dentistry Research Laboratory, Private Setdent Dental Prosthesis Laboratory and Estaş Medical Inc. Laboratory. It was carried out under in vitro conditions (Table 1).

In this study, it is aimed to investigate the effect of different chimney heights on fracture strength and connection strength of ti-base abutments produced from different titanium types.

For this purpose, implants made of Gr 4, Gr 5, Gr 23 titanium materials, ti-base abutments with 3.5, 5.5, 7 mm chimney length and Ti abutment screws made of the same titanium materials were used in our study. Monolithic zirconia crowns were used for the superstructure of the study specimens planned as implant-supported screw-retained prosthesis design. A total of 7 study groups were organised with 11 specimens in each group. In the in vitro phase of the study, the specimens prepared in the study groups were tested for fracture strength with a universal test device.

Sample Preparation

In the in vitro phase of our study, the right 1st molar tooth was removed from the plastic lower jaw model and the toothless crest appearance was given to this area with wax modelling (Figure 2). A 3.8 mm diameter and 13 mm length titanium implant were fixed to the center of the existing edentulous cavity. Ti-base abutments with 2 mm gingival height, 3.5, 5.5- and 7-mm chimney lengths made of different types of titanium were fixed to these implants (Table 2).

A thin layer of scanning spray (Calidia Scan Spray, Essen, GERMANY) was applied on the jaw model and ti-base abutments and placed in a 3D scanning device (Dental Wings 7 Series, Montreal, CANADA) (Figure 2). A digital model was obtained by scanning the spray-coated specimens on the scanning device.

Using CAD/CAM software (Dental Wings 7 Series, MONTREAL, CANADA), sections were taken on the implant and abutment placement area on the digital model and the natural tooth structures and model parts outside this area were removed. Crown designs with homogeneous cement spacing and anatomical structure were made on Ti-base abutment models (Figure 3-5).

For 3.5, 5.5, 5.5, 7 mm ti-base abutments, crowns were produced from polymethylmethacrylate (Imicryl, Imident, TURKIYE) material in order to ensure crown standardization, and their compatibility with the abutments and their forms were checked. The crown designs, whose control phase was completed, were enlarged by 25% and placed on the digital zirconia disc model.

Pre-sintered zirconia discs (Optima, Shenzhen Upcera Dental Co., Ltd., CHINA) were placed in the milling unit (D30, Yena Dent, Istanbul, TURKIYE) and milling was completed with the help of inserts that can move in various axes.

After milling, the samples were carefully removed from the blocks and placed in the sintering furnace (160/1, Protherm Mos, Ankara, TURKIYE). The sinterization procedure was carried out at 900 C° for 2 hours, 1480 C° for 4.8 hours and 900 C° for 1 hour, respectively, in accordance with the manufacturer's recommendations (Figure 6).

The inner surface of the monolithic zirconia crowns was blasted with 50 µm aluminum oxide particles (Korox Bego Bremen, GERMANY) in a sandblaster (Blasmate II, NEY, Yucapia, Ca, USA) (Figure 7) at a distance of 10 mm for 20 seconds under 2 bar pressure. The samples were rinsed and dried with oil-free compressed air and prepared for cementation (Figure 7).

Adhesive resin cement (Theracem Ca, Bisco, Schaumburg IL, U.S.A.) was applied to the inner surface of the sandblasted crown with a uniform thickness. The crowns were placed on the abutments with finger pressure. After irradiation for 2-3 seconds, the cements overflowing from the marginal edges were cleaned with the help of a sonde. In the next stage, the cementation stage was completed by irradiating for 20-30 seconds in accordance with the manufacturer's recommendations (Figure 8).

Titanium implants were fixed in metal blocks with a height of 22 mm and a diameter of 15 mm with autopolymerising acrylic resin (Meliodent, Heraeus Kulzer, GERMANY) mixed in a ratio of 5 g powder to 3.5 g liquid according to the manufacturer's recommendations. The cemented monolithic zirconia and ti-base abutments were torqued with a force of 12 N/cm in the direction recommended by the manufacturer. After torquing, the screw entry path was sealed with Teflon tape (Figure 9).

Specimens Performing Fracture Strength Test

The fracture strength test was performed using a universal testing machine (LR 10K Plus, Lloyd Instruments, Farnham, UK) (Figure 1). The test specimens were placed on a table designed to remain stationary while the force was applied, and this table was fixed to the lower part of the machine. The loading rate was 1±0.5 mm/min according to ISO standards.

In our study, a continuously increasing force was applied until a fracture occurred, which could be detected by visible rupture or sound, at a tip speed of 1 mm/min with a diameter of 4 mm. The test was terminated as soon as the fracture occurred. The data obtained were recorded in Newton (N) in the instrument's own database.

Performing Statistical Analysis

The data obtained after the in vitro test phase was completed were recorded in Newton to the device's own database. SPSS 22.0 (SPSS Inc. Version 22, Chicago, USA) programme was used for statistical analysis of the data and graphs were generated with GraphPad Prism V8.0. One-way analysis of variance and Tukey test were used to compare the fracture strength test data. Differences between groups were evaluated at a significance level of $p \leq 0.05$.

Results

Fracture strength of implant-supported monolithic zirconia restorations designed with 3 different titanium materials and 3 different ti-base chimney heights (Figure 10) (Gr=Grade).

1. When all chimney heights were compared, the lowest fracture strength values were found in the ti-base abutment group made of Gr 4 Ti material.
2. The fracture strength values of the ti-base abutment groups produced from Gr 23 ELI and Gr 5 Ti alloys are similar and there is no difference in the preference of these two Ti alloys.
3. When the chimney heights of Gr 4, Gr 5 and Gr 23 ELI Ti materials groups are compared within themselves, it is seen that the change in the chimney height has no significant effect on the fracture strength values.
4. When the fracture strength test data performed in vitro are evaluated, the lowest average fracture force is within clinically acceptable limits.
5. In our in vitro study, thermocyclus aging technique was not used due to our preference for titanium abutment. Since we only examined static loads in our thesis study, it is necessary to investigate the behavior of the materials compared because of dynamic loading.
6. When the fracture types that occurred in the fracture strength tests in the study were examined, it was determined that fractures occurred in the neck area of the ti-base and in the connection area with the implant. When this situation is evaluated, it is thought that the ti-base titanium strength is not sufficient in the mentioned areas. Therefore, it is recommended to change the material or production method to increase the ti-base strength.
7. When the relationship between connection strengths and Ti alloys was evaluated, it was observed that there was no difference between Ti alloys. However, when 3.5, 5 and 7 mm were compared, it was determined that the connection strength of monolithic zirconia crowns to ti-base abutments increased with the increase in chimney length height. This situation may lead to the desimantation of restorations with short ti-base abutments in single tooth deficiencies in the future.

Discussion

When the findings of our study were evaluated;

The hypothesis that the fracture strength values of the ti-base abutment-implant system produced from Gr 23 ELI titanium will be lower than the fracture strength values of the ti-base abutment-implant systems produced from other titanium types is rejected. The study groups using Gr 23 ELI titanium have similar success with the study groups using Gr 5 titanium.

The hypothesis that the change in Ti-base chimney length will not affect the bond strength values of monolithic zirconia crowns is rejected.

Monolithic zirconia restorations are preferred due to their high fracture resistance.[22] In the in vitro phase of our study, it was aimed to evaluate the fracture strength of abutment-implant systems with ti-base abutments of different shaft lengths and manufactured from different types of titanium. In our study, monolithic zirconia restorations were preferred, considering that early fractures of prosthetic restorations with lower fracture strength would make it difficult to evaluate implant-supported prosthetic systems in this respect.[23] To determine the load-bearing capacity of monolithic zirconia crowns and the amount of acceptable occlusal thickness, it was reported that the fracture strength of restorations increased as the occlusal thickness increased from 0.6 mm to 1.5 mm in monolithic zirconia crowns.

In a systematic review by Wittneben *et al.*[24], screw-retained and cement-retained restorations were compared in terms of survival, mechanical/technical complications, and biological complications. It was reported that the 5-year survival rates of cement and screw-retained restorations were similar and there was no significant difference in failure rates.

In the review, technical complications were statistically more common in cement-retained restorations; however, no significant difference was found between the two retainer types in terms of other technical complications such as abutment, substructure, implant, and abutment screw fracture. In the review, it was reported that biological complications such as fistula and suppuration were more common in cement retained restorations. As a result, it is understood that the type of attachment affects prosthetic success and biological complication rate, although it does not affect the implant survival rate. In addition, screw-retained prostheses can be easily removed during repair, surgical and restorative procedures. The delivery phase of screw-retained prostheses is shorter than cement-retained prostheses. After cementation, it is exceedingly difficult to clean the cement residues in areas where the gingival pocket depth is high. This may cause hard and soft tissue infections and consequently implant loss. When the given Ti-base materials are compared within themselves, there is no difference in the preference for the chimney height. Likewise, there is no difference between Gr 23 Ti ti-base abutments in the choice of 3.5, 5.5- and 7-mm chimney height. In line with this information, screw-retained implant-supported prosthetic design was preferred in our study.

Abutment material and design gain importance in implant-supported fixed prostheses made to meet the functional and aesthetic expectations of patients. The use of zirconia abutments is becoming widespread due to the disadvantageous properties of titanium material in areas with a thin gingival phenotype and in achieving restoration color matching. However, in one-piece zirconia abutments, wear occurs in the titanium implant body due to the hardness difference between the titanium implant body and the zirconia abutment.[25] To solve this problem, a titanium platform called 'ti-base' was produced at the junction of the zirconia abutment with the implant body.[26] With the zirconia core processed on the titanium platform, it is aimed to eliminate the mechanical disadvantages of zirconia and the aesthetic disadvantages of titanium in the implant body. This design is called 'Hybrid Abutment'. In the study of Truninger *et al.*[27], in which they examined the flexural strength of one-piece zirconia and hybrid zirconia abutments, it was stated that titanium platform support contributed positively to the stability of the system[28] reported that the incompatibility of zirconia abutments with the implant body was 3-7 times higher than titanium abutments in their study in which they examined the compatibility of titanium and zirconia abutments in internal surface connections.[29] Reported that hybrid zirconia abutments exhibited higher fracture strength than monolithic zirconia abutments. In a study by Nouh *et al.*[30], it is reported that the fracture strength of hybrid zirconia abutments allows their use in the posterior region. Despite the advantageous features of hybrid abutments, the zirconia core structure prepared on a titanium platform requires an extra laboratory stage. In addition, new zirconia (BruxZir, Glidewell Laboratories, California, U.S.A.) materials with superior light transmittance and aesthetic properties make it possible to use monolithic zirconia crowns on a titanium platform without using a zirconia core structure.[31] In line with the given information, ti-base abutment and monolithic zirconia crown design were preferred in our study.

In the literature, blasting with Al_2O_3 is reported to be the most suitable surface treatment to increase the bond strength between resin cements and the zirconia surface.[43-45] In a systematic review by Gargari *et al.*[46], it was reported that the best procedure for cementation of zirconia restorations in terms of retention was the combination of sandblasting with 50 µm Al_2O_3 and MDP-containing resin cement. In our study, 50 µm Al_2O_3 sandblasting, and MDP-containing resin cement were used in accordance with the given information. It is known that the method of closing the abutment screw entryway before cementation of the restorations to the abutments can affect the retention. There is no clear opinion on whether the abutment screw entryway should be completely or partially closed or left empty. Koka *et al.*[47] reported in their study that complete closure of the screw entry path showed a higher retention value compared to no closure of the entry path. Kent *et al.*[48] examined the effect of partial closure of the screw entry path with autopolymerising resin on retention and reported that this method did not show a significant effect on retention. Analyzed the effect of sealing the screw entryway with 3 different methods on retention in their study. In the first group, the entryway was completely sealed with polyvinylsiloxane, in the second group it was partially sealed with polyvinylsiloxane, and in the third study group, part of the entryway was sealed with polyvinylsiloxane and the remaining part was sealed with composite resin. In the study, it was reported that the removal force was lower in the study group in which the screw entry path was completely closed. In our study, considering that filling the abutment screw entry path may affect the retention values, the abutment screw entry path was closed with Teflon tape. In this way, interaction between the material covering the screw entryway and the cement material was prevented.

After the chewing function, the wear structure in the occlusal region is realized as a surface area, not as a point. For this reason, the size of the fracture tip to be used in the studies gains importance.[50] The sizes of the fracture tips used in the literature vary between 2.65 mm and 6.35 mm. In our study, tests were carried out using a fracture bit with a diameter of 4 mm. In fracture strength tests, the high speed of the fracture bit to be loaded shortens the time required for the progression of microcracks. This situation increases the durability of the material and causes the results obtained to be inaccurate. Therefore, the loading speed should be as low as possible. According to ISO standards, an average loading rate of 1 ± 0.5 mm/min is recommended.[51] In the in vitro phase of this study, a compressive force was applied to the restorations in a direction perpendicular to the ground plane and with a fracture tip speed of 1 mm/min. In the literature, it is recommended to use specimens close to the crown structure instead of bar or disc form in the specimens to be used in fracture strength tests.[52,53] In our study, the restorations were designed in the form of a right first molar crown. To prevent the adverse conditions seen during the milling stage, pre-sintered zirconia blocks, which are preferred instead of fully sintered zirconia blocks.

In another study, it was reported that increasing the thickness of zirconia substructure from 0.5 mm to 2-2.5 mm increased the fracture strength of veneer crowns.[54] It is known that the type of abutment material also affects the fracture strength. In a study by Larsson *et al.*[55] comparing the fracture strength of zirconia and full ceramics, it was reported that the fracture strength values of the specimens cemented on titanium abutments were higher than the specimens cemented on natural teeth. examined the effect of cement types, restoration occlusal thickness, abutment lengths and material types on the fracture strength of implant-supported restorations and reported that the fracture values obtained from the study groups with titanium abutments were higher than those with zirconia abutments. In addition, it was reported that the fracture values obtained from the groups using adhesive cement were higher than the groups using non-adhesive cement.[57] Examined the fracture strengths of monolithic zirconia crowns fixed directly to the implant and monolithic zirconia crowns prepared on a ti-base abutment. In the study, monolithic zirconia crowns were milled from pre-sintered and fully sintered zirconia blocks and crown designs were planned as 2 separate subgroups. In 4 study groups, crowns were prepared in tooth form and fracture strengths analyzed. It was reported that ti-base supported monolithic zirconia crowns (453±25 (PSZ+Ti-base), 439±41 (FSZ+Ti-base)) showed higher fracture values than monolithic zirconia crowns fixed directly to implants (259±23 (PSZ), 140±13 (FSZ), 290±39 52 (Procera)). In our study, it is thought that the use of titanium-containing ti-base abutments, the choice of monolithic zirconia crown design, the choice of occlusal thickness of 2 mm, the use of 50 µm Al_2O_3 sandblasting for surface treatment, and the use of MDP-containing adhesive resin cement in the cementation of the crowns to the ti-base abutments caused the fractures that occurred as a result of the fracture strength test to occur in the ti-base abutments.

Lower first molars, which are the first permanent teeth to erupt in natural dentition, constitute the basis of occlusion and mastication function. Factors such as early exposure of these teeth to caries attacks and the fact that fissure morphology is a crucial factor for caries cause these teeth to be the molars with the highest incidence of caries and tooth loss.[58]

In the studies conducted in the literature, the structures to which loading forces are applied vary. It has been observed that forces are applied directly to the implant body, on the abutment or on the crown structure.[59-63] Although there are differences in the literature in terms of the structure to which the force is applied, it is reported that applying the force on the crown restoration will yield more realistic results.[64] In accordance with the given information, the forces were applied on the crown structure. In the literature, it has been observed that some studies take the tubercle-marginal ridge relationship as the area where the force will be applied, some studies take the tubercle-fossa relationship as the basis, and some studies define the forces directly on the central fossa.[65-68] In our study, forces were defined on the marginal ridges in analyses with vertical loading. In oblique loading, the forces were defined to be applied on the marginal ridges of the buccal tubercles.

Conclusions

Our study was planned to realize monolithic zirconia fractures in the ti-base abutment-implant system. However, since monolithic zirconia fractures did not occur, it was decided to measure the failures in the ti-base neck region in our plan B. In all specimens, deformation of the neck region of the ti-base abutments occurred, and there were no specimens with monolithic zirconia crown fractures. No implant neck fracture was detected in all three groups. According to the data obtained, when the fracture types of the specimens with 3.5 mm ti-base chimney length were evaluated, 72.7% implant-abutment connection fractures were detected in all groups. When the fracture types of the specimens with 5.5 mm ti-base flue length were evaluated, 81.8% implant-abutment connection fractures were detected in Gr 23 ELI Ti study group, 90.9% in Gr 5 Ti study group and 81.8% in Gr 4 Ti study group. In the Gr 23 ELI Ti study group with 7 mm ti-base chimney length, 81.8% of implant-abutment connection fractures were detected.

The fracture strength values of the ti-base abutment groups produced from Gr 23 ELI and Gr 5 Ti alloys are similar and there is no difference in the preference of these two Ti alloys.

When the fracture strength test data performed in vitro are evaluated, the lowest average fracture force is within clinically acceptable limits.

Acknowledgment

None

Conflicts of Interest Statement

The authors declare that they have no competing interests.

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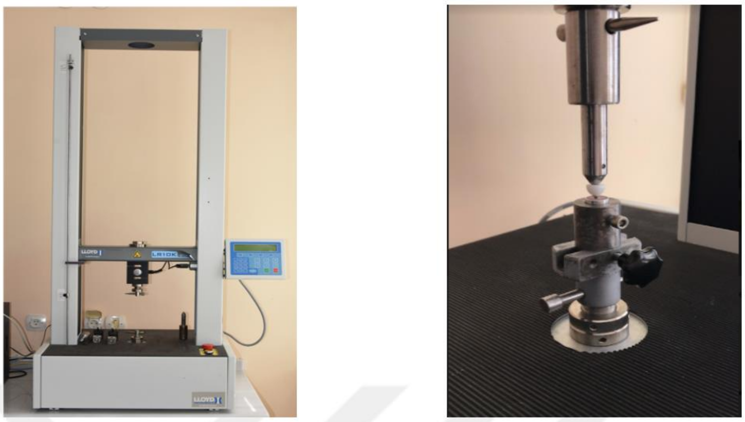
Table 1. Materials and Equipments

Monolithic Zirconia Block	Optima, Shenzhen Upcera Dental Co., Ltd., CHINA
Resin Cement	Theracem Bisco, Schaumburg, Il, U.S.A.
50 µm AL2O3 Sandblasting Material	Korox Bego Bremen, GERMANY
Sand Blasting Unit	Blasmate II, NEY, Yucapia, Ca, U.S.A.
Temporary crown acrylic	Imicryl, Imident, TURKIYE
Autopolymerizing acrylic	Meliodent, Heraeus Kulzer, GERMANY
Grade 4 implant	Estas Medikal A.S., Sivas, TURKIYE
Grade 5 implant	Estas Medikal A.S., Sivas, TURKIYE
Grade 23 implant	Estas Medikal A.S., Sivas, TURKIYE
CAD/CAM Device	7 Series, Dental Wings, Montreal, CANADA
CAD/CAM Cihazı	D30, Yena Dent, Istanbul, TURKIYE
Sinterization unit	160/1, Protherm Mos, Ankara, TURKIYE
Strength test unit	Lr30 K; Lloyd Istruments Ltd, Farnham, ENGLAND
Strength test analysis program	Nxygen Plus

Table 2. Fracture Locations According to Ti-base Chimney Length and Titanium Type for the Study Groups

Titanium Type	Ti-base Chimney Length	Ti-base Neck Fracture	Implant-Abutment Connection Fracture
Grade 5	3.5	3	8
Grade 5	5.5	1	10
Grade 4	3.5	3	8
Grade 4	5.5	2	9
Grade 23 ELI	3.5	3	8
Grade 23 ELI	5.5	2	9
Grade 23 ELI	7	2	9



(A) (B)

Figure 1. Universal Test Device (A) and Fracture Test (B)

Figure 2. Dimensional Jaw Models

Figure 3. Crown Design (Buccal) (A) and Crown Design (Apical) (B)

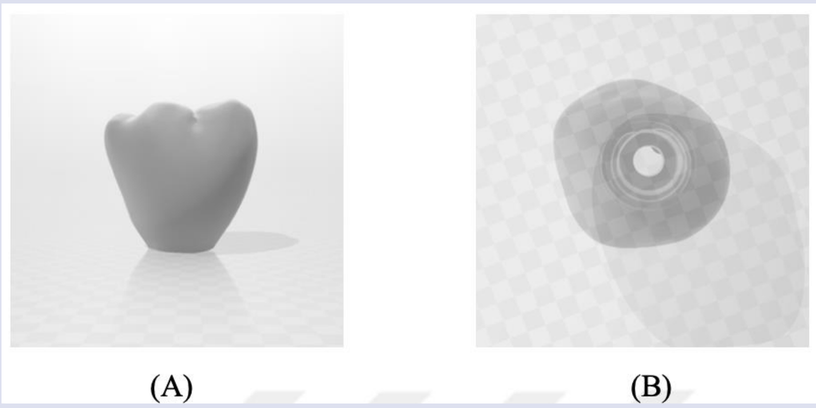


Figure 4. Zirconia Disc (A) and Zirconia Disc (B)

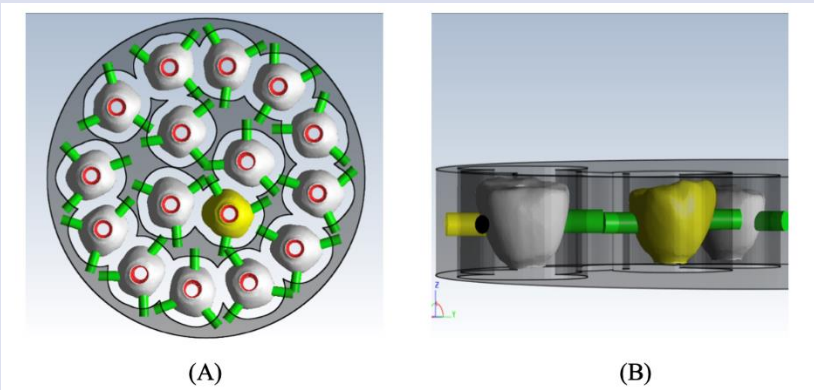


Figure 5. Zirconia Disc (A) and Zirconia Disc (B)

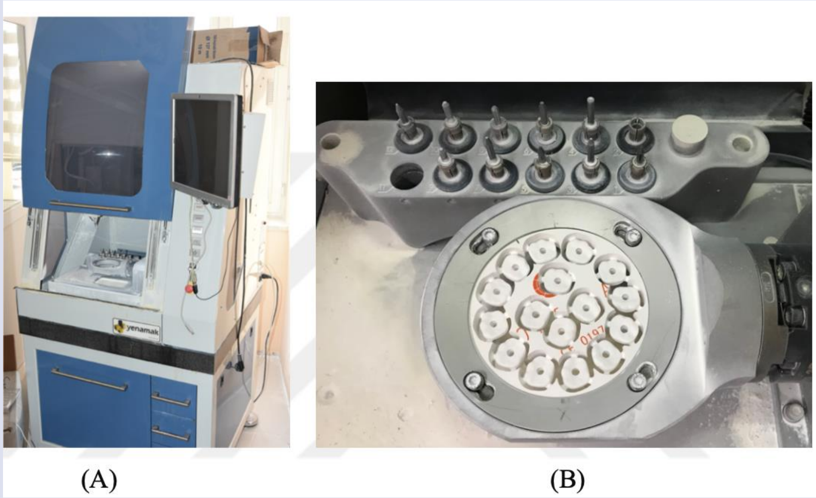


Figure 6. Zirconia Crowns

Figure 7. Shot Blasting Device (A) and Shot Blasting Process (B)

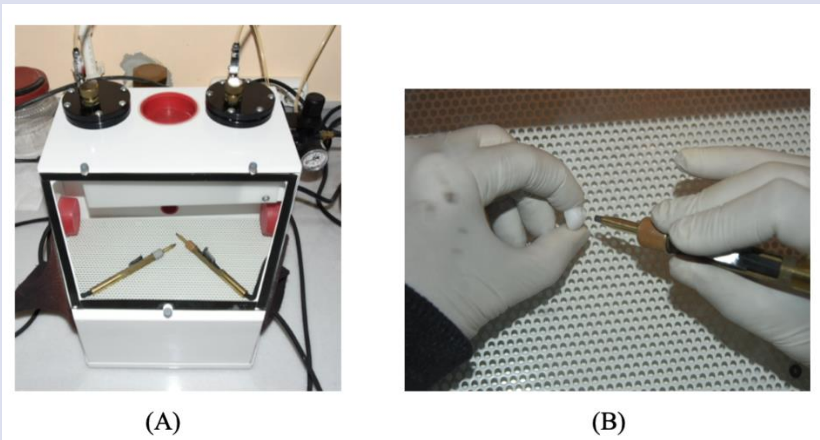


Figure 8. Resin Cement Material (A) and Polymerization of Resin Cement (B)

Figure 9. Autopolymerising Acrylic Resin (A) and Torquing process (B)

Figure 10. Graph of Fracture Strength According to Implant Material and Ti-Base Chimney Length

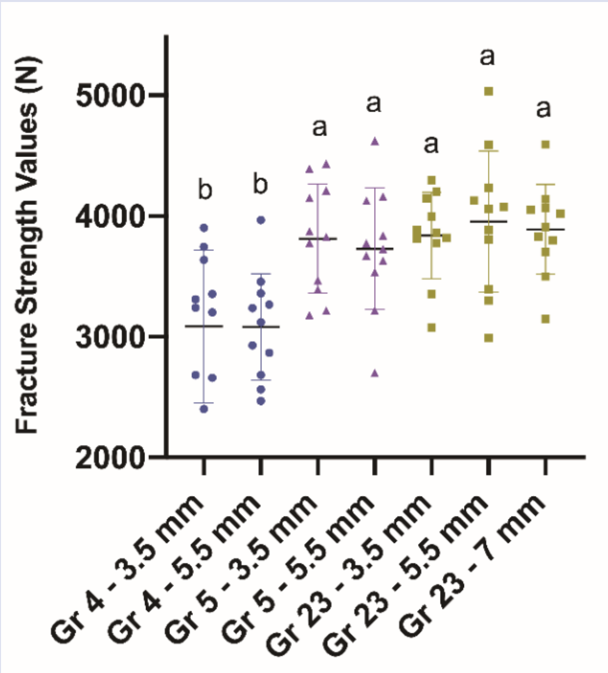


Figure 11.