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Research Article

EVALUATION OF THE CONNECTIONS OF DIFFERENT TYPE OF ABUTMENTS TO THE IMPLANT BODY UNDER MASTICATION

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ABSTRACT

Objective: This study aims to compare the biomechanical behavior of the implant-abutment connection against in-vitro loading in the use of Straight and Angled standard fabricated abutments and CAD/CAM abutments in a locally designed and produced special connection.

Materials and Methods: Ti Grade5 Straight abutment was used in the first group, 25° Angled Ti Grade5 fabricated abutment was used in the 2nd Group, and TiBase abutment was used in the 3rd Group. The implant diameter was used as 4.8 mm, and each sample was fixed on the implant manually or using a torque wrench. The crowns were cemented or screwed to the superstructures, which were torqued or manually tightened to 30 Ncm twice a day apart, and the first images were taken with the Micro-CT device. Four-year use of each sample was simulated in 1000000 cycles in the chewing simulator application. Micro-CT was again used to measure implant-abutment contact areas after loading.

Results: There is a significant difference between all groups, except for the range in the tightening group with 30Ncm torque before simulation, only on one side and at the internal measurement point.

Conclusion: When we look at the compatibility of the connection screw with the abutment before and after the chewing simulation; In general, it has been noticed that the fabricated straight abutments and Universal Ti-Base abutments have a tighter connection gap, while the connection of Angled abutments is weaker. When looking at the compatibility of the abutment contact areas with the implant body before and after the chewing simulation; It has been observed that the tightest connection values are generally created by CAD/CAM and Straight abutments, to a greater extent than screw fit.

Keywords: Implant-abutment connection, Micro-gap, Micro-ct

INTRODUCTION

Although implant-supported dentures are a successful treatment option, some failures may be encountered, as in every treatment. Abutment-related complications; Problems in the adaptation between the implant and the abutment material, abutment angulation, abutment screw loosening or screw fractures. Implant-abutment connection; It is very important for the long-term success and stability of the prosthesis. Incompatibility between these components is an issue that should be taken into consideration because, in addition to mechanical problems such as screw loosening and damage to the internal screw threads, it also causes biological complications due to microorganism colonization in the interior of the implant. As a result of these biological complications, inflammation occurs in the peri-implant tissues, followed by pain, marginal bone loss, and in the worst case scenario, deterioration of osseointegration may result (1).

The internal connection formed by the abutment and extends up to 4 to 6 mm into the implant bodies. This design increases the adaptation between the bodies and the abutments (2). In the internal connection, the first part of the implant in contact with the abutment resists most of the forces coming from the outside, thus eliminating the majority of the forces applied to the screw, significantly reducing the adaptation loss and ensuring the continuity of the stability of the implant abutment connection (3). The internal connection has superiority over the external connection in ensuring the adaptation of the implant and abutment connection, preventing torque loss and resisting screw loosening (4,5).

Ideally, implants should be placed parallel to axial forces. Due to improper interjaw relationships or improper bone structure, the long axis of the placed implant and the long axis of the planned prosthetic superstructure may be incompatible, and angled abutment is used in prosthetic restorations in order to provide ideal aesthetics and position by combining these two planes. Angled abutments are frequently preferred in all-on-four and all-on-six treatment concepts used in the treatment of edentulous patients, for aesthetic reasons, to ensure distance from anatomical formations, and to provide convenience for the patient and physician by reducing treatment costs and duration (6-8). When the implant is not placed parallel to axial forces, angled abutments are used. Although the use of angled abutments makes it easier to provide aesthetics by giving the final shape to prosthetic restorations, the use of angled abutments is more prone to creating transverse forces during the applied loads compared to straight abutments and this leads to the formation of off-axis forces.

The aim of present study is that a comparison of the mechanical situation of the implant and abutment connection against chewing in the use of straight and angled prefabricated abutments in a "deep internal hexagonal" connection and customized abutments produced in Universal Ti-Base and CAD/CAM technique. The clinical importance of present study is that observe the effect of chewing for implant-abutment connection fit. The null hypothesis of present study is; 1) Since the geometry and clearance area of the connection part and internal structures of the implant body used in the study are the same, there are not any differences between the post-connection micro gaps of all abutment designs, 2) in terms of abutments, there are not any differences for the gap between the groups tightened by hand and tightened with a torque wrench. 3) after the chewing simulation, there are no differences either.

MATERIALS AND METHODS

In this study, NucleOSSTM T6 Bone level implants (Turkey) were used, with a diameter of 4.8 mm, a conical internal hex structure with a 140 degree connection and made of pure titanium (Grade 4) compatible with international standards. Ti Grade5 fabricated straight, fabricated 25° Angled and personal CAD/CAM supports were used to connect to the implant bodies. Each material was divided into subgroups, each of which was tightened manually and with a torque wrench, and a total of 6 groups, each with n = 9 samples, were included in the study (Table 1). All hand tightening operations were

Table 1. Test groups

Group	Abutment and Connected Implant Body Diameter (mm)	Tightening Type
1	**T6 WD051** Straight - Ti Grade5 prefabricated abutment(Diameter: 4,8)	Manual
2	**T6 WD141** 25° Angled Ti - Grade5 prefabricated abutment (Diameter: 4,8)	Manual
3	**T6 32804** CAD/CAM abutment (Diameter: 4,8)	Manual
4	**T6 WD051** Straight - Ti Grade5 prefabricated abutment (Diameter: 4,8)	30 Ncm
5	**T6 WD141** 25° Angled Ti - Grade5 prefabricated abutment (Diameter: 4,8)	30 Ncm
6	**T6 32804** CAD/CAM abutment (Diameter: 4,8)	30 Ncm

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Table 2. Before and After Chewing Simulator Values of the Gap Between the Screw and the Abutment According to "Tightening Type – Abutment" Factors (μm)

			SVD1	SVD2	SVM1	SVM2
	Tightening Type	Abutment	Mean±Standard Deviation	Mean±Standard Deviation	Mean±Standard Deviation	Mean±Standard Deviation
Before	Manual	T6 WD051 Straight	15.90^{A}±0.109	15.46^{A}±0.178	16.37^{A}±0.178	16.59^{A}±0.123
		T6 WD141 25° Angled	18.59^{B}±0.098	19.01^{B}±0.217	18.94^{B}±0.402	19.68^{B}±0.183
		T6 32804 CAD/CAM	15.34^{C}±0.162	15.36^{A}±0.278	15.16^{C}±0.339	16.34^{A}±0.470
	30 Ncm	T6 WD051 Straight	11.51^{A}±0.149	11.47^{A}±0.156	12.07^{A}±0.114	12.42^{A}±0.204
		T6 WD141 25° Angled	14.57^{B}±0.180	14.43^{B}±0.157	14.65^{B}±0.341	14.67^{B}±0.424
		T6 32804 CAD/CAM	11.55^{A}±0.109	11.11^{A}±0.178	11.90^{A}±0.178	11.83^{A}±0.123
After	Manual	T6 WD051 Straight	28.54^{A}±0.109	28.45^{A}±0.178	28.54^{A}±0.109	30.28^{A}±0.123
		T6 WD141 25° Angled	34.86^{B}±0.098	33.98^{B}±0.217	34.86^{B}±0.098	36.07^{B}±0.183
		T6 32804 CAD/CAM	33.61^{C}±0.162	32.33^{C}±0.278	33.61^{C}±0.162	34.73^{C}±0.470
	30 Ncm	T6 WD051 Straight	28.78^{A}±0.149	27.44^{A}±0.156	28.78^{A}±0.149	29.80^{A}±0.204
		T6 WD141 25° Angled	43.64^{B}±0.180	46.30^{B}±0.157	43.64^{B}±0.180	44.21^{B}±0.424
		T6 32804 CAD/CAM	37.45^{C}±0.109	35.06^{C}±0.178	37.45^{C}±0.109	37.91^{C}±0.123

* The difference between the average value shown with a different letter in each "Tightening Type" subgroup is statistically significant ($P<0.05$).

performed by the thesis researcher with maximum personal force (Groups 1-3). All tightening with a torque wrench was performed by the same researcher at a value of 30 Ncm according to manufacturer's instructions (Groups 4-6).

Standard metal crowns with the same form as the prosthetic superstructure were used to load the created mechanisms with the chewing simulation. To avoid motion artifacts, all samples were stayed in a vertical position in a mold with an inner diameter of 18.53 mm with using a paralelometer. For this purpose, the implant in each sample was fixed using autopolymerizing acrylic (Vertex-Dental, Netherlands) and embedded in the block mold. Groups with abutment screws tightened by hand force were tightened by a single physician twice, 24 hours apart, and standardized by applying the same force value for each sample. Torque group samples were completed by the same physician twice, with an interval of 24 hours, by applying a torque value of 30 Ncm according to the manufacturer's instructions. As the final stage of sample preparations; Cementation of metal crowns was performed with tgimplaCEM dual-cure resin cement (Technical&General, London, UK), which is specially produced for implant applications.

Micro-CT scanning of the samples, Bruker SkyScan 1275 (Bruker Skyscan, Kontich, Belgium) device with high resolution scanning capacity was used in the Micro-CT laboratory of Ankara University Faculty of Dentistry. For scanning parameters, the rotation step was determined as 0.5 for 100 kVp, 100 mA and 10 μm pixel size. After the scans were completed, each scanned sample was individually reconstructed using NRecon (NRecon, Version 1.6.7.2, Skyscan, Kontich, Belgium, 2020) software. Using NRecon software (Skyscan, Kontich, Belgium, 2020), images were reconstructed to show cross-sections of the samples. Additionally, CTAn (v.1.17.7.2, Bruker micro-CT, Kontich, Belgium) and the DataViewer program (v1.5.6.2; Bruker Micro-CT) were used to analyze and segment the three-dimensional models. The number of sections could be standardized for all samples and the same section corresponding to the center of the implants in all directions could be analyzed for each implant. By transferring the projections of the three-dimensional reconstruction samples to the CTAn (CTAn, 2020) software, from these points twice, before and after the chewing simulator; A comparison of measurements taken at certain points from the sagittal and coronal directions was made. For volumetric measurements, the upper and lower borders of the gap were marked with the software, and the gap boundaries to be calculated were determined in each of the remaining sections separately using the function called regions of interest (ROI). Then, the ROI created for each section was automatically combined by the software to create the volume of interest required for three-dimensional analysis.

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Table 3. Before and After Chewing Simulator Values of the Gap Between the Abutment and the Implant Body According to "Tightening Type – Abutment" Factors (µm)

			AVD1	AVD2	AVM1	AVM2
	Tightening Type	Abutment	Mean±Standard Deviation	Mean±Standard Deviation	Mean±Standard Deviation	Mean±Standard Deviation
Before	**Manual**	T6 WD051 Straight	$18.13^{A}\pm0.315$	$18.41^{A}\pm0.335$	$16.59^{A}\pm0.171$	$18.97^{A}\pm0.337$
		T6 WD141 25° Angled	$20.76^{B}\pm0.096$	$20.82^{B}\pm0.103$	$19.38^{B}\pm0.362$	$20.87^{B}\pm0.291$
		T6 32804 CAD/CAM	$21.32^{C}\pm0.339$	$21.44^{C}\pm0.375$	$19.82^{C}\pm0.092$	$21.52^{C}\pm0.380$
	30 Ncm	T6 WD051 Straight	$17.54^{A}\pm0.120$	$17.45^{A}\pm0.232$	$17.64^{A}\pm0.258$	$18.39^{A}\pm0.196$
		T6 WD141 25° Angled	$18.12^{B}\pm0.300$	$17.97^{B}\pm0.308$	$17.29^{B}\pm0.158$	$18.96^{B}\pm0.437$
		T6 32804 CAD/CAM	$16.54^{C}\pm0.604$	$15.94^{C}\pm0.281$	$17.25^{B}\pm0.281$	$16.63^{C}\pm0.280$
After	**Manual**	T6 WD051 Straight	$30.13^{A}\pm0.315$	$30.76^{A}\pm0.335$	$28.64^{A}\pm0.171$	$31.84^{A}\pm0.337$
		T6 WD141 25° Angled	$37.76^{B}\pm0.096$	$44.51^{B}\pm0.103$	$39.68^{B}\pm0.362$	$43.62^{B}\pm0.291$
		T6 32804 CAD/CAM	$38.33^{C}\pm0.339$	$42.13^{C}\pm0.375$	$39.11^{C}\pm0.092$	$42.27^{C}\pm0.380$
	30 Ncm	T6 WD051 Straight	$31.54^{A}\pm0.120$	$32.14^{A}\pm0.232$	$34.93^{A}\pm0.258$	$34.15^{A}\pm0.196$
		T6 WD141 25° Angled	$42.14^{B}\pm0.300$	$44.73^{B}\pm0.308$	$22.49^{B}\pm0.158$	$49.97^{B}\pm0.437$
		T6 32804 CAD/CAM	$37.54^{C}\pm0.604$	$37.98^{C}\pm0.281$	$43.19^{C}\pm0.281$	$40.25^{C}\pm0.280$

* The difference between the average value shown with a different letter in each "Tightening Type" subgroup is statistically significant (P<0.05).

The samples with the first Micro-CT scan were placed in the chewing simulator (Esetron, Turkey) device, and each sample was subjected to mechanical loading of 100 N with a frequency of 2 Hz at a speed of 45 mm per second from a distance of 5 mm vertically, and 1000 N with intraoral simulation at 37°C water temperature. Four years of use in 1000000 cycles is simulated (9). Following this process, the same samples were scanned again using the same parameters with the SkyScan 1275 device to evaluate the adaptation of the implant parts.

Data were evaluated using Analysis of Variance (ANOVA) for the size of the microvoid expressed as mean ± standard deviation. TUKEY HSD multiple comparison test was applied according to the distribution of the results. Statistical significance level was determined as P < 0.05. Homogeneity of variances was tested with Levene test.

RESULTS

In the part of this study where connection fit was evaluated using Micro-CT, sample measurement values were first divided into two groups: linear and volumetric (Figure 1). Linear measuring points; It is divided into subgroups to evaluate the gap between the connection screw and the abutment (Screw Vertical Distal - SVD and Screw Vertical Mesial - SVM) and to evaluate the gap between the implant body (Abutment Vertical Distal - AVD and Abutment Vertical Mesial - AVM). By transferring the projections of the three-dimensional reconstruction samples to the CTAn (CTAn, 2020) software, the sagittal measurements taken from these

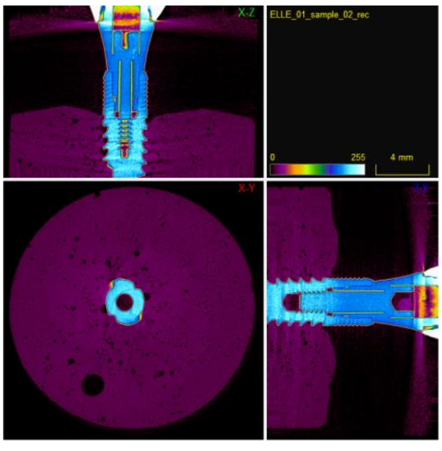

Figure 1. Micro-ct evaluation for screw and abutments.

points were compared twice, before and after the chewing simulator (Table 2).

When the abutment and the implant body were evaluated in terms of compatibility according to the results of the TUKEY HSD multiple comparison test conducted for the "Tightening Type - Abutment" factors before and after the chewing simulator; There is a significant difference between all groups, except for the range in the tightening group with 30Ncm torque before simulation, only on one side and at the internal measurement point (AVM1). At the AVM1 point, which differs from the general, the straight abutments showed a statistically significant difference compared to the other two abutments. According to the data obtained, the lowest range values are; It was determined in the measurements before the chewing simulation in straight and CAD/CAM abutments tightened with a torque of 30 Ncm (Table 3).

DISCUSSION

Gastric NHLs, which constitute 1-4% of all GI When the results of this study were critically evaluated, it was observed that although the parts sitting on the implant body had the same geometry, the abutment superstructure design especially affected the connection compatibility. Additionally, in almost all samples, notable differences were detected in the compliance values after the chewing simulation compared to before the simulation. Considering all these data, the null hypothesis of our study was partially accepted. 1) Although the geometry and gap area of the connection internal structures of the implant bodies used in the study are the same, contrary to our hypothesis, different abutment designs revealed different microgap values and our first hypothesis is invalid, 2) This hypothesis is rejected, as it is generally seen more in the groups compressed with a torque wrench before being exposed to the chewing simulation. 3) This hypothesis is rejected because the amount of gap in all groups after the chewing simulation is greater than the first measurements.

Although the popularity of implant-supported prostheses is increasing day by day, this increase; has brought about the frequency of encountering various complications. Frequently reported mechanical complications; Failures of prosthetic components, loss of retention, screw loosening and implant fracture. Screw-related complications in implant-supported restorations are frequently reported in the literature, and screws are known as the weakest link of these restorations. It has been observed that various complications occur as a result of screw loosening. Additionally, loose screws are more prone to breakage under load, leading to long-term prosthesis complications (10, 11).

He et al. aimed to examine the microcavities at the implant and abutment interface and the change in the contact area for two different connection designs under angular cyclic loading. In the two-piece implant system consisting of a conical connection group and an external hexagonal connection group, the samples were subjected to cyclic loading by applying increasing loads up to 220 N. After loading, the samples were scanned using Micro-CT and the resulting level of leakage was evaluated using silver nitrate, a high-contrast penetrating agent. In this study, it was observed that the conical connection showed more resistance to the formation of microcavities at the implant and abutment interface compared to the external hexagonal connection (12).

Zipprich et al. aimed to examine the mechanical situation of different implants and abutment connections with X-ray imaging. 20 different implant systems, with different implant sizes and different implant abutment connections, were used in the study. The samples were subjected to static and dynamic force (200 N). The width and length of the gap between the implant-abutment interface and different implant-abutment connection types were compared. As a result of the study, it was observed that eight of the 20 implant systems with conical connections had no measurable microgaps under 200 N load, while all other systems with straight abutment connections had measurable gaps in static and dynamic loading. Using x-ray imaging, reduced microvoid formation and micromobility have been detected in systems with tapered implant-abutment connections compared to systems with straight connections (13).

Hamilton et al. compared the titanium, CAD/CAM abutments with prefabricated abutments of five different implant types (Brånemark System, NobelReplace RP, Astra Tech OssesoSpeed 4.0, Straumann Bone Level RC, Straumann Standard Plus RN). As a result of the study, the average difference of 1.86 μm between the CAD/CAM abutments on the gold synOcta and Straumann Standard Plus implant was found to be statistically significant. For the remaining implant types, less than 0.4 μm difference was found between prefabricated abutments and CAD/CAM abutments and no statistical difference was observed. A statistically significant mean difference of 34.4 μm (gold) and 44.7 μm (titanium) was found between CAD/CAM abutments and prefabricated abutments on Straumann Standard Plus implants. An average difference of 15 µm was observed on the NobelReplace implant and the CAD/CAM abutment, and this value was found to be statistically significant. All other groups had differences of less than 4 µm and this value was not found to be statistically significant. In most systems evaluated, CAD/CAM abutments demonstrated compliance comparable to prefabricated abutments. In our study, when looking at the compliance with chewing simulation; In general, it has been noticed that the fabricated Straight implant abutments exhibit a tighter connection gap, while the connection of Angled abutments is weaker (14).

Focusing on implant abutments and taking into account the advantages, disadvantages and complications of CAD/CAM abutments, the study aims to discuss the use of custom abutments in the anterior region (CAD/CAM). It has been concluded that the use of CAD/CAM concepts in production provides advantages over both stock abutments and traditional cast custom abutments. CAD/CAM abutments are available in a variety of materials and different attachment platforms to the implant to meet aesthetic, functional and biological demands. CAD/CAM technology is a system that should be considered in the restoration of dental implants in the aesthetic zone (15).

The compatibility of the implant body - abutment - screw combination is not only the parameters related to the superstructure success of implant-supported prostheses, but also affects the survival time of the implant body in the bone. All in vitro studies in this field, including the Micro-CT analysis method used in this study, are efforts to collect data to increase the survival time of implant-supported prostheses in the mouth and thus to give ideas to both manufacturers and users. In addition, after prosthetic applications are completed and implant-supported prostheses are used, perhaps the most difficult prosthetic complication to compensate for is screw fractures. For this reason, choosing designs with the highest durability during the use process will increase the comfort and safety of use. For this reason, it is expected that the in vitro study, examining the most important parameters of implant systems related to oral survival and testing them in a large sample group, will also be predictive of clinical success.

CONCLUSION

Within the limitations of present study;
In general, screw has been noticed that the fabricated straight abutments exhibit a tighter connection gap, while the connection of Angled abutments is weaker. When evaluating the compatibility of the screw within the body, the adaptable result among all groups was generally observed to be the most incompatible group, the CAD/CAM group. Another observed fact is that the screw connection under function decreases significantly over time. Implant body has been observed that the most strict adaptation values are generally created by CAD/CAM and straight abutments to a greater extent than the abutment compliance. It has been determined that aging negatively affects the connection values in terms of the fit of the abutment to the implant body.

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Authorship contributions
YDE and MAK planned and designed the study. YDE and BA collected and processed the data. YDE, MAK, BB, and KO contributed to the data analysis and interpretation. YDE conducted the literature search. YDE, MAK, BA, and BB drafted the manuscript.

Data availibity statement
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declaration of competing interest
There is no conflict of interest in this study.

Ethics
Since resources obtained from humans or animals were not used in this study, ethics committee approval was not obtained.

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