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Original Research Article

Effect of Preload on Different Implant Abutments in Terms of Screw Loosening

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ABSTRACT

Aim: This study aimed to compare the mechanical behavior of the implant-abutment connection in cases where appropriate preloading is performed or not.

Materials and Methods: A total of 54 bone-level implants with a diameter of 3.5 mm were employed in this study. Each group was further divided into subgroups, each of which was tightened manually and with a torque wrench, and a total of six groups were tested, three of them being control groups. Manual tightening was performed by the same researcher with maximum manual force and tightening with a torque wrench was performed with a value of 30 Ncm by the same researcher. Sample measurement values in which connection compliance is evaluated using micro-CT.

Results: The total space volume between the screw and the implant body (single torque minimum 0.32 mm^3) decreased significantly in the samples tightened for the second time (minimum 0.20 mm^3). Still, no difference was observed between tightening manually or with a torque wrench a second time, except for the angled abutment group.

C**onclusion:** Tightening a second time after preload significantly reduced the gap values, especially when using a torque wrench. Therefore, tightening the implants repeatedly using a torque wrench after preloading (retightening) plays a significant role in clinically preventing screw loosening and consequently major clinical problems such as screw fractures.

Keywords: Dental Implants; Preload; Screw Loosening

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INTRODUCTION

Implant-abutment connection is crucial for the long-term success and stability of the prosthesis.[1] 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 causes biological complications due to microorganism colonization in the interior section of the implant.[2]

According to data obtained from *in vitro* studies, an increase in stability was observed with the use of internal connection.[3-9] In the design with internal connection, a lower incidence of abutment screw loosening was observed compared to external connection. It was stated that this situation provided a biomechanical advantage.[7,10] Since the loading force is not completely applied on the screw in the internal conical connection, it is possible for the abutment screw to reach a larger preload value in this connection type. The solid design of the friction-lock mechanism and friction-fit connection provides greater resistance to fracture and deformation under oblique compression loading compared to passive-fit designs.[11]

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An inevitable gap occurs between the implant and abutment, since cold fusion does not occur when the abutments are compressed in the passive-fit connection.[12-18] The gap may cause micromobility during clinical loading. Micromobility may create stress on the screw, causing loss of compression achieved by preload and loosening of the abutment. The harmful micromobility level has been determined by many researchers to be between 50 and 150 µm. It is possible for micromobility values measured beyond this level to result in bone loss in the part of the placed dental implants corresponding to the crestal bone region.[16]

Currently, many studies indicate that the inadequate tightening or loosening of the screw, the screw design, non-passive prosthetic structures or prosthetic extensions, inclined prosthetic components, incompatible parts, destruction of the support bone, lateral forces, and bruxism cause screw loosening.[19,20] The situation is disturbing for the physician and patient alike. Screw loosening can lead to fractured implant components and biological complications. One of the main causes of screw loosening is occlusal and lateral loads that are transferred from the implant to the bone.[21] Screw complications are more common with single-tooth implant restorations compared to multi-unit restorations.[22] Other factors that may cause screw loosening include the screw being tightened with inadequate force, insufficient prosthetic superstructure, the presence of incompatible superstructure and prosthetic components, overload, and bone elasticity.[12,23,24]

The preload applied to the screw increases the fatigue resistance and ensures the locking of the implant and abutment connection.[25] Preload enables the tightened abutment screw to transmit linear force to the abutment-implant body and hold these components together. Considering the elongation that occurs when torque is applied, the screw can be considered to have elastic properties similar to a stretched spring.[26] Preload is determined by three factors. These factors are the amount of torque, the shape of the screw head, and the type of material of which the screw and the abutment are made.[12] By applying sufficient preload to the screw, less mobility and fewer screw-loosening problems are observed at the abutment and screw interface.[27-29] Applying preload to the screw increases the resistance of the abutment to fatigue and ensures the locking of the implant and abutment connection. Occlusal forces applied to implant-supported prostheses cause changes in the preload applied to the abutment screws. This situation may result in loosening the abutment screw.[30,31] The head of the abutment screw is generally flat. The screw head produced in a conical shape reduces the compression and tensile forces occurring in the screw threads. A flat-head screw design distributes forces more evenly in the head and thread parts of the screw than a conical-shaped screw head design.[25,32]

All *in vitro* studies in this field, including the micro-CT analysis method employed in this study, are efforts to collect data to increase the survival time of implant-supported prostheses in the mouth and present ideas to manufacturers and users. The aim of this study was to examine the mechanical behavior of uniquely designed and manufactured dental implants and their different superstructure abutments while functioning. The aim was to compare the mechanical behavior (compatibility values) of the implant-abutment connection in cases where appropriate preloading was performed or not, on the grounds that they can distribute the loads that will fall on them in different directions in the use of straight and angled prefabricated abutments and custom abutments produced in CAD/CAM technique in a “deep internal hexagonal” connection when two different thickness implants were employed. The null hypothesis of this study was that in groups manually tightened, there will be no difference in the gap between the first compression and the second compression, but in the samples torqued with 30 Ncm as preload, relaxation will be observed after the first compression.

MATERIALS AND METHODS

A total of 54 NucleOSSTM T6 (Şanlılar Tıbbi Cihazlar Medikal Kimya San. Tic. Ltd. Şti., Türkiye) bone-level implants with a diameter of 3.5 mm were used in this study. The T6 implant is manufactured from pure titanium (Grade 4) that complies with international standards. Since this study was conducted *in vitro*, an ethics committee approval was not required. The internal structure of the T6 implant has a conical internal hex structure with a 140-degree connection. As the superstructure, Ti Grade 5

Table 1. Test Groups.

Group	Abutment and Connected Implant Body Diameter (mm)	Tightening Type
E1	T6 SD047 Straight - Ti Grade 5 prefabricated abutment (diameter: 3.5)	Manual
E3	T6 SD134 25° Angled Ti - Grade 5 prefabricated abutment (diameter: 3.5)	Manual
E5	T6 32804 CAD/CAM abutment (diameter: 3.5)	Manual
T9	T6 SD047 Straight - Ti Grade 5 prefabricated abutment (diameter: 3.5)	30 Ncm
T11	T6 SD134 25° Angled Ti - Grade 5 prefabricated abutment (diameter: 3.5)	30 Ncm
T13	T6 32804 CAD/CAM abutment (diameter: 3.5)	30 Ncm

straight abutment T6 SD047 straight, 5 mm platform diameter abutment, 25° Angled Ti Grade 5 fabricated abutment (T6 SD134 angled, 5 mm platform diameter) and CAD/CAM abutments were used, with n = 9. Each group was further divided into subgroups, each of which was tightened manually and with a torque wrench, and a total of six groups were tested, three of which were control groups (Table 1). Manual tightening was performed by the same researcher with maximum manual force and tightening with a torque wrench was performed at a value of 30 Ncm by the same researcher. Scans of the sample, which was compressed both manually and using a torque wrench, were completed 24 hours after both the first compression (before) and the second compression (after) to see the preload loss. The samples, whose first scans were completed, were immediately subjected to second compression.

For micro-CT scanning of the samples, a Bruker SkyScan 1275 (Bruker Skyscan, Kontich, Belgium) device with high-resolution scanning capacity was employed in the micro-CT-Laboratory of Ankara University Faculty of Dentistry. For scanning parameters, the rotation step was determined to be 0.5 for 100 kVp, 100 mA, and 10 µm pixel size. A 1 mm thick copper filter was employed to prevent radiological artifacts that may occur during shooting. These corrections were ring artifact correction, beam hardening, post-alignment, and smoothing at the optimum level for each sample. NRecon software and CtAn (Version 1.17.7.2, SkyScan) were used to visualize and quantitatively measure samples using the modified algorithm described by Feldkamp *et al*., and to obtain axial, two-dimensional, 1000 × 1000 pixel images. For reconstruction parameters, ring artifact correction and smoothing were fixed at 10, and beam artifact correction was set to 60%. Contrast limits were applied following SkyScan's instructions. Using NRecon software (Skyscan, Kontich, Belgium, 2020), images obtained by the scanner were reconstructed to show two-dimensional cross-sections of the samples. A total of 1014 cross-sectional images were reconstructed from the entire volume.

After the scans were completed, each scanned sample was individually reconstructed using NRecon (NRecon, Version 1.6.7.2, Skyscan, Kontich, Belgium, 2020) software. Dataviewer software was employed to obtain study images from the center of the dental implants, where measurements were made in coronal and sagittal directions. This software made it possible to select the region of interest (ROI) and the desired number of sections for the selected region. As a result, 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. The software was then employed to perform the measurements. All measurements were made by the same researcher. Since the presence of minor radiographic artifact precluded the use of any automated instrumentation, all measurements were taken manually, and measurement points were standardized to minimize errors. After the cross-sections of the projections of the samples were obtained through reconstruction, these cross-sections were transferred to the CTAn (CTAn, Version 1.17.7.2, Skyscan, Kontich, Belgium, 2020) software for mathematical analysis. 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). These sections were processed using the software's histogram, employing a grayscale of 0-255 to represent only the space to be calculated as a white object, while the rest of the area was blackened to

exclude it from calculation. Subsequently, three-dimensional volumetric calculations were performed (Figure 1). All measurements were performed by a single examiner blinded to the group allocation.

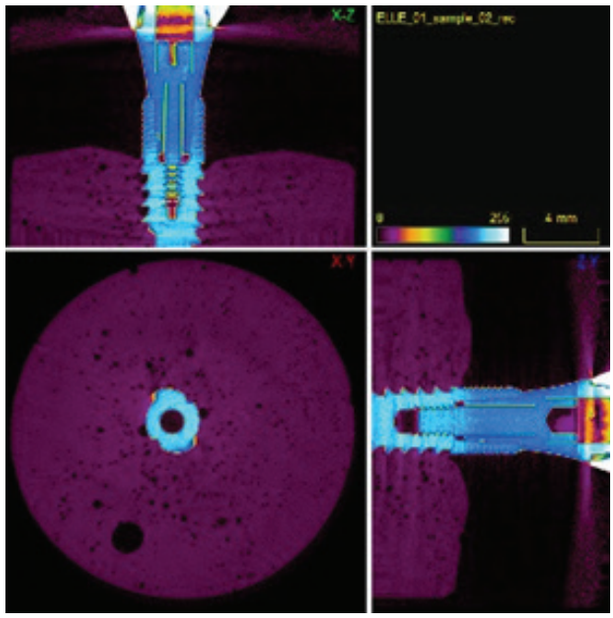

Figure 1. Micro-CT Images of implant body - abutment assemble.

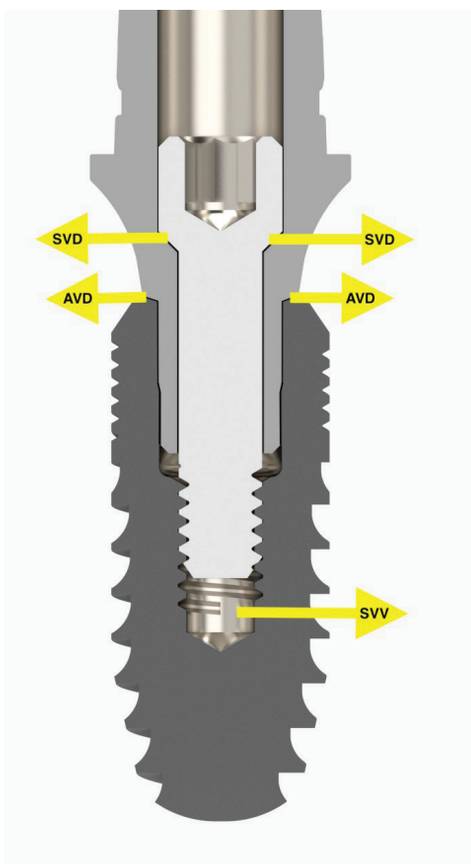

Figure 2. Measuring Points.

Sample measurement values in which connection compliance was evaluated using micro-CT were primarily divided into two groups: linear and volumetric. Linear measuring points were divided into subgroups to evaluate the gap between the connection screw and the abutment (Screw Vertical - SVD) and between the connection screw and abutment and the implant body (Abutment Vertical - AVD). In volumetric measurements, measurement areas were the main space (Screw Vertical Volume (SVV) between the screw and the screw slot in the implant body was evaluated (Figure 2).

Shapiro–Wilk test was used to assess the normality of data distribution. Data were evaluated using analysis of variance (ANOVA), with the size of the microgap expressed as mean ± standard deviation. The TUKEY HSD multiple comparison test was applied for post-hoc pairwise comparions. Statistical significance level, P, was determined as < 0.05. Homogeneity of variances was tested with the Levene test. Comparisons were made according to the factorial variance analysis technique, and primarily the “Tightening Type - Abutment” binary interaction, that is, the mutual interaction of the factors, was evaluated statistically.

RESULTS

A before and after comparison of sagittal SVD preload compression according to the “Tightening Type - Abutment” factors were made according to the factorial variance analysis technique. While all abutment groups differed significantly from each other in screw fit, whether manually tightened or torqued, it was determined that second tightening reduced the gap between the screw and the abutment in all groups and all placement techniques (Table 2). It was observed that the abutment-implant body compatibility relationship also reduced the gap with second tightening (Table 3). The total space volume between the screw and the implant body significantly decreased in samples that were tightened for the second time. On the other hand, no difference was observed between tightening manually or with a torque wrench a second time, except for the angled abutment group (Table 4).

Table 2. Descriptive Statistics of Screw Vertical Distal (SVD) Values According to Tightening Type.

Characteristic	Tightening Type	Abutment	CORONAL Right (µm)	CORONAL Left (µm)
			Mean ± SD	Mean ± SD
SVD- Before	Manual	T6 NR042 Straight	20.42^{A}±0.14	20.38^{A}±0.14
		T6 SD134 25° Angled	23.47^{B}±0.28	23.03^{B}±0.27
		T6 32804 CAD-CAM	18.76^{C}±0.25	18.52^{C}±0.25
	Torque wrench	T6 NR042 Straight	24.92^{A}±0.49	25.43^{A}±0.31
		T6 SD134 25° Angled	18.91^{B}±0.20	19.53^{B}±0.30
		T6 32804 CAD-CAM	17.41^{C}±0.24	17.83^{C}±0.17
SVD- After	Manual	T6 NR042 Straight	17.03^{A}±0.14	17.39^{A}±0.14
		T6 SD134 25° Angled	20.07^{B}±0.28	20.03^{B}±0.27
		T6 32804 CAD-CAM	15.38^{C}±0.26	15.53^{C}±0.25
	Torque wrench	T6 NR042 Straight	12.49^{A}±0.25	12.70^{A}±0.16
		T6 SD134 25° Angled	15.69^{B}±0.18	16.23^{B}±0.30
		T6 32804 CAD-CAM	14.19^{C}±0.26	14.53^{C}±0.17

*P<0.05 indicates the level at which statistical difference was determined.
**The superscripts (A, B, C) indicate whether there was a statistical difference between the groups based on letter similarity or difference.

Table 3. Descriptive Statistics of Abutment Vertical Distal (AVD) Values According to Tightening Type.

Characteristic	Tightening Type	Abutment	CORONAL Right (µm)	CORONAL Left (µm)
			Mean ± SD	Mean ± SD
AVD- Before	Manual	T6 NR042 Straight	20.49^{A}±0.21	21.00^{A}±0.13
		T6 SD134 25° Angled	23.60^{B}±0.38	23.52^{B}±0.19
		T6 32804 CAD-CAM	24.31^{C}±0.24	24.44^{C}±0.23
	Torque wrench	T6 NR042 Straight	34.52^{A}±0.77	34.57^{A}±0.49
		T6 SD134 25° Angled	22.08^{B}±0.14	22.28^{B}±0.14
		T6 32804 CAD-CAM	21.67^{B}±0.17	22.14^{B}±0.27
AVD- After	Manual	T6 NR042 Straight	17.11^{A}±0.23	17.51^{A}±0.14
		T6 SD134 25° Angled	20.26^{B}±0.40	20.02^{B}±0.19
		T6 32804 CAD-CAM	20.92^{C}±0.24	20.94^{C}±0.23
	Torque wrench	T6 NR042 Straight	17.24^{A}±0.37	17.30^{A}±0.25
		T6 SD134 25° Angled	18.40^{B}±0.13	18.42^{B}±0.14
		T6 32804 CAD-CAM	17.98^{C}±0.19	18.30^{B}±0.27

*P<0.05 indicates the level at which statistical difference was determined.
**The superscripts (A, B, C) indicate whether there was a statistical difference between the groups based on letter similarity or difference.

Table 4. Descriptive Statistics of Volume SVV Values According to Tightening Type.

Tightening Type	Abutment	Volume (mm3) SVV_Before	Volume (mm3) SVV_After
		Mean ± SD	Mean ± SD
Manual	T6 NR042 Straight	0.52^{A}±0.1	0.22^{A}±0.15
	T6 SD134 25° Angled	0.60^{A}±0.23	0.30^{A}±0.23
	T6 32804 CAD-CAM	0.53^{A}±0.05	0.23^{A}±0.05
Torque wrench	T6 NR042 Straight	0.32^{A}±0.04	0.20^{A}±0.00
	T6 SD134 25° Angled	0.76^{B}±0.05	0.23^{A}±0.05
	T6 32804 CAD-CAM	0.78^{B}±0.04	0.24^{A}±0.05

*P<0.05 indicates the level at which statistical difference is determined.
**The superscripts (A and B) indicate whether there is a statistical difference between the groups based on letter similarity or difference.

DISCUSSION

When the results of this study were critically evaluated, it was observed that, although the parts placed on the implant body were of the same geometry, the abutment superstructure design affected the connection compatibility, especially with the preload application. In addition, the null hypothesis of this *in vitro* study was partially accepted, as the second compression reduced preload relaxation in both the torque wrench and manually tightening groups.

The support or abutment can be attached to the implant externally or internally. In the first implant and superstructure design model proposed by Brånemark, the implant and abutment were connected using a 0.7 mm external hexagonal connection type.[36] Over the years, complications such as loosening of the implant abutment screw and the formation of microvoids and microbial penetration at the implant-abutment interface have been observed because of using this connection type. The partial success rate highlighted the need for some modifications.[37] According to data obtained from in-vitro studies, an increase in stability has been observed with the use of internal connections. In designs with internal connections, a lower incidence of support screw loosening was observed compared to external connections, and this has been stated to provide a biomechanical advantage.[7-9] Marginal bone loss was found to be greater in implants with external connections compared to those with internal connections. The implant support structure connected with an internal hexagon connection provides a wider force distribution area compared to an external hexagon structure, thus exhibiting higher stability.[15]

Screw loosening between the implant and the abutment is a widely reported problem in the literature.[19,20] When torque is applied, the contact between the screw threads and the inner surface of the implant causes embedment relaxation, also known as the settling effect. This means that the preload value decreases on these surfaces after a few minutes, as if the watch winder is discharging. It is considered normal for the initial torque value to decrease between 2% and 10%.[20,30] It has been observed that the removal torque value decreases in cases where tightening and loosening are applied at successive intervals.[11] It was observed that there was a significant decrease in the torque values of the abutments after mechanical cycling in the hexagonal connection compared to the Morse taper connection.

Loosening and fracture are potential problems for abutments and fixation screws. The frequency of screw loosening reached 12.7% in single crowns and 6.7% in fixed partial dentures. Loosening the abutment screw brings various complications. Various complications may occur, such as soft tissue advancing into the space between the loosened implant abutment and the implant, leading to fistula formation and infection of the soft tissue. Additionally, loose screws are more prone to breakage under load, which can lead to long-term prosthetic complications.[33] While abutment screw loosening was observed at a rate of 1.5% in abutments with internal connection, due to the biomechanical advantage, it was observed as 7.5% in abutments with external connection. Some researchers reported the loosening between different connection types, some suggested different screw designs, and some suggested different screws. They compared their materials, and some compared their surface coatings. In addition to the effect of the torque applied and the re-torquing of the screw after it was initially torqued, the number of times a screw can be torqued and whether this reduces screw loosening has been investigated by researchers.[10]

El-Sheikh *et al*.[33] aimed to investigate the effect of abutments on screw loosening by measuring their torque value at different angles and neck lengths before and after dynamic cyclic loading using a digital torque device. A total of 90 bone-level implants with a conical hybrid connection, 4.5 mm in diameter and 10 mm in length, were used. According to the abutment angle, they were divided into three groups: GI 0°, GII 15°, and GIII 25° abutments. Each group was divided into two subgroups, subgroup A (2 mm) and subgroup B (4 mm), each consisting of 15 samples. Each implant and abutment were placed vertically in acrylic resin using a stainless-steel cylindrical mold. Initial analysis was performed with the abutment screw tightened to a torque of 30 Ncm twice at 10-minute intervals using a digital torque indicator. RTV before and after cyclic loading of the abutment screws was measured in Newton centimeters using a digital torque gauge. One hundred thousand cycles

of eccentric dynamic cyclic loading were applied at 130 N at a rate of 1 Hz, 5 mm from the central axis of the implant. The percentage of removal torque loss (%RTL) before and after dynamic cyclic loading was calculated and statistically analyzed using SPSS version 20. As a result of this study, it was stated that screw loosening increased with increasing abutment angle and neck length. *In vitro* studies have indicated that tapered and non-tapered abutments provide adequate resistance to maximum bending forces and fatigue testing. However, better coverage, fewer micro voids, and stability were observed in conical supports. Additionally, this study indicated that compared to angled abutments, the conical hybrid connection is more biomechanically stable when used with straight abutments.

Parnia *et al*.[34] compared the experience factor in manually tightening of implant abutments, observing instructors and postgraduate students as they made implant abutment connections. In the study, they measured the tightening values with the help of a torque meter. It was observed that male practitioners applied more torque than females, and professors applied more than students. Additionally, an increase in clamping force was observed as age progressed.

Seloto *et al*.[35] looked at the effect of sealing gel use on the vertical compliance of the implant abutment interface and determined that the maximum gap value before mechanical loading with gel use was 5.55 µm and after mechanical loading was 4.59 µm. Differences in measurement points and gel application make these values different from those in our study.

The compatibility of the implant body – abutment – screw combination is not only one of the parameters related to the superstructure success of implant-supported prostheses but also affects the survival time of the implant body in the bone. For this reason, the connection compatibility and evaluation of microgaps that will arise due to this connection have been investigated using many methods, from finite element analysis to the evaluation of microorganism leakage, some of which can be seen in the discussion section of this *in vitro* study. In addition, after prosthetic applications are completed and implant-supported prostheses are used, screw loosening and fractures are perhaps the most difficult prosthetic complications to compensate for. Therefore, selecting designs with the highest durability during use will enhance user comfort and safety. The use of a single connection type and manual compression by a single researcher are among the limitations of this study. Nevertheless, our *in vitro* study, which examined the most important parameters related to the oral survival of implant systems and tested them in a large sample group, is likely to be clinically informative.

CONCLUSION

Within the limitations of this study,
1. Considering both the connection screw and the abutment, the loosening as a result of the first tightening with the torque wrench is greater than with the manually tightened, and the gap value increases.
2. Tightening a second time after preload significantly reduced the gap values, especially when a torque wrench was used. Therefore, tightening the implants using a torque wrench after preload plays an important role in preventing screw loosening.

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Ön Yüklemenin Farklı İmplant Abutmentlerindeki Vida Gevşemesine Etkisi

ÖZET

Amaç: Bu çalışmanın amacı; uygun ön yüklemenin yapıldığı veya yapılmadığı durumlarda implant-abutment bağlantısının mekanik davranışını karşılaştırmaktır.

Gereç ve Yöntemler: Bu çalışmada çapı 3.5 mm olan toplam 54 adet kemik seviyesi implant kullanılmıştır. Her grup, her biri manuel ve tork anahtarıyla sıkılan alt gruplara ayrılmış ve ilk üçü kontrol grubu olmak üzere toplam 6 grup test edilmiştir. Manuel sıkma aynı araştırmacı tarafından maksimum kişisel kuvvetle, el tornavidası ile sıkma ise aynı araştırmacı tarafından 30 Ncm değerinde gerçekleştirilmiştir. Bağlantı uyumunun mikro-BT kullanılarak değerlendirildiği örnek ölçüm değerleri elde edilmiştir

Bulgular: Vida ile implant gövdesi arasındaki toplam boşluk hacmi, tek sıkılan örneklere göre (minimum 0.32 mm^3) ikinci kez sıkılan örneklerde önemli ölçüde azalmıştır (minimum 0.20 mm^3). Bununla birlikte açılı abutment grubu dışında, manuel veya tork anahtarıyla ikinci kez sıkma arasında bir fark gözlenmemiştir.

Sonuç: Ön yüklemeden sonra ikinci kez sıkma, özellikle tork anahtarı kullanıldığında boşluk değerlerini önemli ölçüde azalttı. Bu nedenle, ön yüklemeden sonra implantları tork anahtarı kullanarak ve tekrarlayarak sıkmak klinik olarak hasta ağızında vida gevşemesini dolayısıyla vida kırıkları gibi büyük klinik problemleri önlemede önemli bir rol oynar.

Anahtar Kelimeler: Dental İmplant; Ön yükleme; Vida Gevşemesi