EGYPTIAN DENTAL JOURNAL
www.eda-egypt.org

Vol. 69, 487:495, January, 2023

Print ISSN 0070-9484 • Online ISSN 2090-2360

Fixed Prosthodontics and Dental Materials

Submit Date : 10-10-2022 • Accept Date : 07-11-2022 • Available online: 1-1-2023 • DOI : 10.21608/edj.2022.167394.2286

INFLUENCE OF THERMO-MECHANICAL AGING ON STRAIGHT VERSUS ANGLED MULTI-UNIT ABUTMENTS SCREW JOINT STABILITY

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ABSTRACT

Purpose: Evaluate the screw joint stability of the straight versus angled Multi-Unit (MU) abutment following dynamic cyclic loading and thermo-cycling aging.

Methods: This study compared abutment screws reverse torque values (RTVs) using three different angles (0°, 17°, and 30°) after cyclic loading and thermocycling. The samples comprised 21 full crowns supported by internal hex implant fixture and multi-unit abutments divided into three groups (A, B & C), representing abutment different angulations. For data analyses, the significance level was set at $p > 0.05$ (CI 95%).

Results: Paired t-test showed that the mean RTV was significantly lower following aging for each angle (*P*-value = 0.000). The three angulation groups' abutment screw RTVs differed significantly, with the lowest RTV detected at the 17 degree angulation MU Abutment.

Conclusions: The performance of angled abutments in regards to removal torque values were less than that of straight abutments, yet, have generally been satisfactory. Dynamic cyclic loading and thermocycling had a significant effect on RTV of implant abutments.

KEYWORDS: Screw loosening; Multi-unit abutment; Joint stability; All-on-Four; Angled Abutment.

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INTRODUCTION

The “all-on-four” strategy was established to make the best use of existing remaining bone in atrophied jaws, enabling immediate function while attempting to avoid regenerative processes, which increase treatment expenses and complications [(1)]. Starting from its introduction, the treatment became a viable treatment option and standard of care for the severely compromised jaw bone with cumulative survival rate of 92-100% [(2)].

In simply put, the all-on-four concept entails four or more implants are placed in a fully edentulous jaw. The two anterior implants are positioned axially, while the posterior implants are angled to take full advantage of implant length while avoiding anatomic structures [(3)]. The implants are splinted together to support a screw retained hybrid fixed restoration using multi-unit implant abutments (MU Abutment). In addition to the anterior straight MU abutment, the posterior ones allow an angulation of 17° and 30° and have different tissue heights and diameters [(4)]. The necessity for angulated abutments in implant dentistry has turn out to be accepted, this rose with the need to achieve functional and aesthetic restorations because of the patients high expectations. Since then, numerous numbers of manufacturers present abutments alternating from 0 to 60 degrees plane of alignment angulations [(5)].

Although the “all-on-four” treatment concept procedure was reported to have a high level of patient satisfaction [(6)], several studies conveyed biological and mechanical complications associated with this treatment concept and the angulation of the abutments [(7, 8)]. Creating a superstructure with a passive fit is one of the most important objectives of implant-based prosthesis. However, failing to attain this passive fit will increase the stress falling on implants which can eventually lead to failure of the proposed treatment plan, along with implant components fracture [(9)].

Fracture of screw, insufficient occlusal force dissemination, and failure of osseointegration can all result from screw loosening. Furthermore, screw loosening during chewing would cause micro-motion at the interface of implant-abutment, worsening the microleakage and causing a slew of biological issues [(10, 11)]. Long-term clinical success is reliant on the stability of the implant-abutment screw and the prosthetic-abutment retaining screw (joint assembly) and their resistance to occlusal forces [(12)].

The hypothesis of the current study is that there is no difference in screw joint stability of straight and angled Multi-Unit (MU) abutments (17° and 30°) implant supported single crowns after thermo-cycling and dynamic cyclic loading. Therefore, the goal of this research study is to compare the screw joint stability of the straight MU abutment against that of the angled Multi-Unit (MU) abutment after dynamic cyclic loading and thermo-cycling of the abutment and prosthetic screws.

MATERIALS AND METHODS

A total of twenty-one implant (n = 7) were distributed into three equal groups. Using an alpha (α) level of 0.05 (5%), a beta (β) level of 0.05 (5%), i.e. power=95%, and the effect size (f=0.805) calculated basing on results of Xia et al[(10)]; the sample size was set up to be a total of (21) samples randomized according to abutment degree of angulation into three main groups. The sample size was calculated using G*Power version 3.1.9.2. Each assembly consisted of an internal hex implant fixture measuring in diameter 4.1 mm × 10 mm in length (T6 32152 Fixture NucleOSS Izmir. Turkey) with corresponding 5.0 mm Multi-unit Single Restoration Hex Abutments divided into three groups: **Group (A)** consisted of seven implants with straight MU Abutment (T6 32438 MU Abutments, Single Tooth Restorations, Hex, NucleOSS. Izmir. Turkey). **Group (B**) consisted of seven implants with 17 degree angulation MU Abutment (T6 32441 MU abutments, Single Tooth Restorations, Hex, NucleOSS. Izmir.Turkey). **Group (C)** consisted of seven implants with 30 degree angulation MU Abutment (T6 32443 Multi Unit Abutments, Single Tooth Restorations, and Hex. NucleOSS. Izmir. Turkey). The implant-abutment assemblies were then mounted in an epoxy-resin mold. Fixture was inserted in the prepared mold filled with clear acrylic resin (Orthoplast; Vertex, Zeist, The Netherlands). The upper most margin of implant abutment interface was 3mm above the resin mold level. The mold was filled with resin increment by increment over a vibrator to avoid polymerization shrinkage.

Full Anatomical wax pattern (Bego, Germany) was constructed over the three different angulation abutments (0, 17, 30 degrees) by the same technician forming the three main groups A, B, & C **(Figure 1)**. For duplication of the wax pattern to construct the rest of the crowns, the three abutments with (0, 17, 30 degrees) angulation and over it the fabricated wax pattern were each inserted using a paralleling surveyor to mount the abutments within the long axis of the implant fixture inside dental stone type III (Whipmix, USA). After finishing and smoothing the stone holding the abutment with the overlying wax pattern, it was inserted in a mold that was then filled with light impression material (Panasil Kettenbach. Germany). After impression material setting, the previously constructed wax pattern was removed and the space created was filled with burn-out wax (Bego. Germany) poured in replication mold to replicate the exact form of the superstructure for standardization.

Fig. (1) Group (A) sample straight abutment with wax pattern superstructure

Base metal alloy (Ni-Cr) crowns were cast over multi-unit abutment after fabricating wax pattern (Bego, Germany). A total of twenty-one base metal crowns were fabricated for all groups. An abutment screw was used to connect superstructures to fixtures embedded in epoxy resin moulds. Screw tightening was done to the recommended value by the manufacturer at 25 Ncm torque (Prosthetic guide, Nucleoss Dental implant, Izmir Turkey) for all samples before start of testing at the time of connection to simulate the clinical procedure. Further tightening was done 3 times with 10 minutes intervals to prevent settling effect. Samples fitted inside a mold were subjected to a 10,000 thermal cycle (SD Mechatronik Thermocycler, GmbH, Feldkirchen-Westerham, Germany) which was applied every 30 seconds between 5°C and 55°C, with a 30 second stay time in each bath and a 20 second gap between baths at air temperature. A force of 200 N at 1.0 x 10^6 cycle intervals that is equivalent to 20 kg for 250.000 cycles stimulating 1 year of service in the mouth, were applied using cyclic loading machine (CS-4 SD Mechatronik Thermocycler, GmbH, Feldkirchen-Westerham, Germany) with a stylus positioned at the center of crown **(Figure 2, 3)** along the implant long axis in a vertical direction. Screw loosening was evaluated after cyclic loading procedure. Removal torque values were measured using a digital torque device after cyclic loading (BTGE50CN, Tohnichi, Japan). The driving torque tester had a counterclockwise rotation and a speed of 3 rpm. The sample record was kept for statistical purposes. The ANOVA test was used to compare the three groups. To compare the load and RTV within the same group, a paired T-test was used. SPSS for Windows 18.0 (SPSS Inc., Chicago, Illinois, USA) was used for statistical analysis.

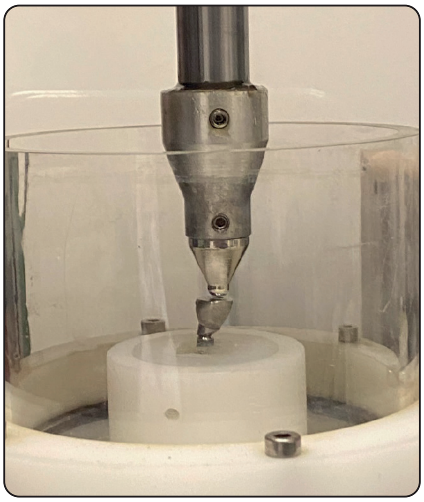

Fig. (2): Effect of chewing simulator on 17 degree angled MU abutment

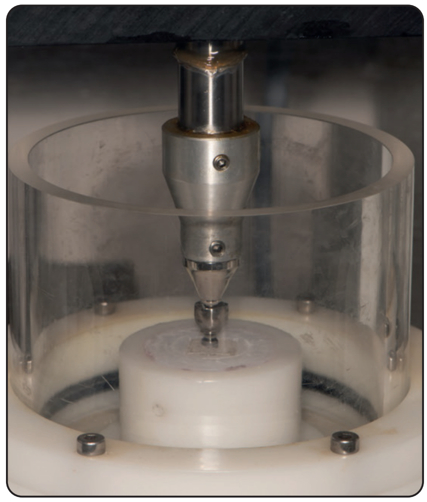

Fig. (3): Effect of chewing simulator on straight MU abutment

RESULTS

Test of normality was applied to Removal Torque Values (RTV) in each group. Both Shapiro-Wilk test and Kolmogorov-Smirnov test with Lilliefors Significance Correction showed that RTV were normally distributed in each group, either before testing or after testing (*P*-values > 0.05), **(Table 1).** There was significant difference between the two time points (before testing and after testing) in mean RTV using repeated measures ANOVA (*P-value* = 0.000), **(Figure 4).**

Paired t-test showed that the mean RTV was significantly lower after aging testing for each abutment angle **(Table 2, Figure 5)**. For the implants with straight MU Abutment (0 torque), the mean RTV for the before testing was 25.134 Ncm compared to 20.078 Ncm after aging (*P*-value = 0.000). Similarly, for implants with 17 degree angulation MU Abutment had a mean RTV of 25.135 Ncm at the before aging compared to 16.778 Ncm after aging (*P*-value = 0.000). Finally, the implants with 30 degree angulation MU Abutment had a mean RTV of 25.153 Ncm at the before compared to 18.73 Ncm after testing (*P*-value = 0.000). For all statistical analyses, the level of significance was set at 5%, and the confidence interval was set at 95% (95% CI).

After thermocycling and Cyclic loading of the samples, significant difference was detected among the 3 degrees in the mean RTV (*P*-value = 0.000) **(Table 3)**. Using Tukey's method, the mean RTV for the 0 degree was 20.078 Ncm, and it was significantly greater than that of the 17 degree (mean RTV = 16.778 Ncm, *P*-value = 0.000) and that of the 30 degree (mean RTV = 18.37 Ncm, *P*-value = 0.002). Which was also significantly greater than that of the 17 degree (*P*-value = 0.003).

TABLE (1): Tests of normality for the removal torque values (RTV)

Torque		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	*p*-value	Statistic	df	*p*-value
Before testing	0	0.163	7	.200*	0.937	8	0.584
	17	0.201	7	.200*	0.896	8	0.267
	30	0.128	7	.200*	0.983	8	0.975
After testing	0	0.107	7	.200*	0.992	8	0.997
	17	0.186	7	.200*	0.900	8	0.288
	30	0.200	7	.200*	0.877	8	0.177

This is a lower bound of the true significance.
a Lilliefors Significance Correction ***df = degrees of freedom***

TABLE (2): Summary statistics and paired t-test of removal torque values (RTV) for each group at each time point

Torque	Time	Mean (Ncm)	SD (Ncm)	Paired t-test *P*-value	95% Confidence Interval	
					Lower Bound	Upper Bound
0	Before testing	25.134	0.108	0.000	25.060	25.208
	After testing	20.078	0.761		19.460	20.695
17	Before testing	25.135	0.104	0.000	25.061	25.209
	After testing	16.778	0.832		16.160	17.395
30	Before testing	25.153	0.089	0.000	25.079	25.226
	After testing	18.370	0.920		17.752	18.988

SD = standard deviation, Ncm = Newton-centimeter

TABLE (3): Summary statistics and One-way ANOVA test of removal torque values (RTV) between the three groups at each time point

		Mean (Ncm)	SD (Ncm)	One-way ANOVA *P*-Value	95% Confidence Interval for Mean		Tukey as Multiple comparison test		
					Lower Bound	Upper Bound	0	17	30
Before testing	0	25.134	0.108	0.910	25.044	25.224	NA	NA	NA
	17	25.135	0.104		25.048	25.222	NA	NA	NA
	30	25.153	0.089		25.078	25.227	NA	NA	NA
After testing	0	20.078	0.761	0.000	19.441	20.714	1	0.000	0.002
	17	16.778	0.832		16.082	17.473	0.000	1	0.003
	30	18.370	0.920		17.601	19.139	0.002	0.003	1

Ncm = Newton-centimeter, SD = standard deviation, ANOVA = analysis of variance

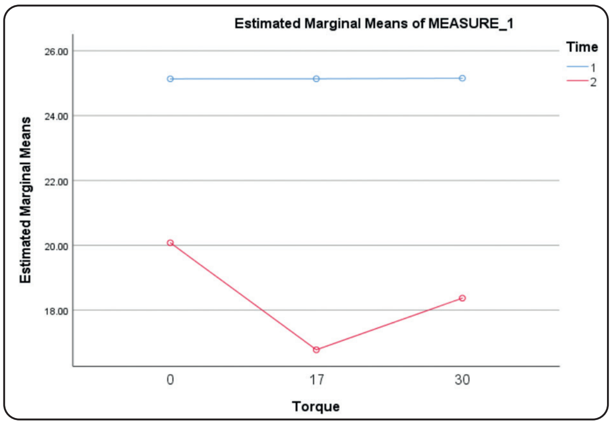

Fig. (4): Plot graph comparing RTV for each degree at two time points

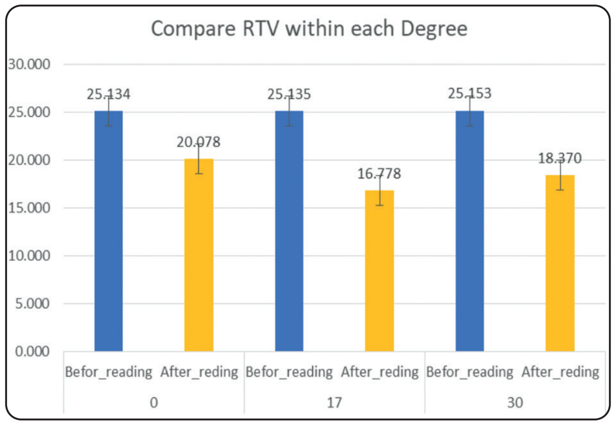

Fig. (5): Comparing RTV for each degree between two time points

DISCUSSION

Load distribution on bone, implants, and abutment assembly are all topics that frequently come up in biomechanical discussions. The stress analysis is a topic of great interest in the arena of implant dentistry. This study highlights the influence of different angled multi-unit abutments for all-on-four implant cases on the screw joint stability, which will help clinicians to select most appropriate abutment for different clinical situations. Research was conducted in-vitro for easier inspection of screw loosening due to the evaluation's accuracy, as well as the effort in standardizing and repeating the results acquired for strain measurement in-vivo [(13)]. In this study, a clinical situation was duplicated to assess the consequence of different multi-unit abutment angulation and their screw loosening effect on implant-supported crowns after thermocycling and cyclic loading. Three different angulations 0, 17, & 30 degrees were examined. The null hypothesis was rejected because the mean abutment screw removal torque values of the three angulation abutment groups differed significantly.

There was an advocate for angled abutments use as a simplified and easier solution for the management of challenging clinical situations. The introduction of angled abutments was to fulfil the aesthetic demands and functional purposes of the patients. The load on angled abutments is usually off-axis, which increases concerns about angled abutment performance when such an unfavorable loading procedure is employed [(14)]. The most common problem with screw-retained restorations is abutment screw loosening. It has been reported that screw loosening affects approximately 6% of implant restorations. Arch position, Para-functional habits, cantilever designs, occlusal table design, implant location, non-passive seating and insufficient or too much screw torque can produce forces that will intensify the possibility of screw loosening [(15)]. Bacterial migration and settlement along the abutment-implant junction, loss in the crestal bone, and screw fracture, abutment fracture, or even implant body fracture are all mechanical and biological complications of a loose screw abutment. When torque is generated inside an abutment screw due to rotational action, it lengthens the screw, creating a tensile force seen between shank and threads known as preload [(15)].

Preload is certainly connected with the screw tightening torque values. The abutment screw will be in a state of elastic deformation; consequently, greater tightening torque and excessive preload does not always show better outcomes. When the preload go beyond the abutments screw material yield's limit, the screw will be permanently distorted and fails to do its function, by this means it will lose or even fracture the screw [(16)]. For that reason, the ultimate preload is commonly 60%-80% of the yield strength of the screw material [17]. The loss of preload can be noticed 2-3 minutes after tightening, even if there was no external force [18]. The process of losing the preload due to the connection process is called the settling effect [19, 20]. This explains why, even when not loaded, all screws suffer from a preload loss ranging from 2% to 10% at the start. As a result, it was acclaimed that screws be tightened again 10 minutes after the initial tightening. The initial settling is reduced from this point on, and the preload is maintained [20]. A study concluded that retightening the screws after 10 minutes decreased the torque percentage loss by 17% and that retightening perform as a positive influence in maintaining the preload [17].

Parallelometer (surveyor) was used to guarantee standardization of abutment position in the stone models. All study models were prepared by the same dental laboratory technician. Pouring Epoxy resin around implants rather than drilling of the fixture in the simulated block was performed in this study to ensure that the epoxy resin and implant threads are completely integrated. Drilling into the resin after hardening could have led to the existence of micro-gaps between the fixture and the epoxy which could affect the stress transmission during mechanical cyclic loading affecting removal torque values [21]**.** The optimal torque is very important for guaranteeing the stability of the screw joint abutment [22]. In this study a digital torque gauge was used to tighten abutment screw to recommended Value by manufacturer to RTV before and after thermal cycling and cyclic loading. This technique was used by several authors the error produced by this device was found approximately 2% [17, 20, 22].

Using Tukey's 'Honest Significant Difference' method, the mean RTV for the 0 degree was 20.078 Ncm, and it was significantly greater than that of the 17 degree (mean RTV = 16.778 Ncm, *P*-value = 0.000) and that of the 30 degree (mean RTV = 18.37 Ncm, *P*-value = 0.002). Also, the mean RTV of the 30 degree was significantly greater than that of the 17 degree. In the current study, the 17° group revealed the lowermost mean RTV compared to the 0 and 30 degrees angles, which was not expected to be lower than 30 degree which was expected to be least RTV as a reason of the higher applied torque as the angle of the abutment increases. The mean difference of RTV before and after cyclic loading and thermocycling of the 17° group was the highest between the three groups.

A likely clarification for this outcome is probably due to the design of the universal screw driver, where inspection of the screw driver head showed a sphere designed tip that converts into cylindrical design moving down the tip. The unevenness of the driver head design at the top and bottom allowed for closer configuration between the screwdriver head and abutment screw at the 17° angulation, but this unevenness in design transferred less torque to 30 degree angle compared to the 17 degree while transferring the least torque to the screw at 0°. Regarding the information that addressed the frequency of screw loosening in association to angled abutments, the information is infrequent and limited. During the 8-year controlled RCT with angulations ranging from 0° to 45°, Sethi et al 2002 observed no implant fractures or screw loosening[23]. Cavallaro and Greenstein in 2011 mentioned that screws loosened commonly, up to 45 percent. They hypothesised that the high rate of screw loosening was due to evidence that abutment screws were manufactured of titanium and that appropriate torqueing devices were unavailable. They found that using current gold abutment screws, which produce a higher screw preload when appropriately torqued, reduced the frequency of screw loosening significantly [24].

Another possible explanation is the occlusal forces and strain created by different angles, when screw loosening occurs it is important to recognize the reason behind the screw becoming loose. In specific, special consideration should be done when examining the occlusion [13]. Angled abutments are often used when the implant is not positioned parallel to the long axis force, but, they are more expected to build up tensile force under masticatory loads, consequently causing in off-axis forces [25]. The 17 degree angled abutment might have transferred more occlusal strain on the screw than the 30 degree angled abutment.

Our study results were against those of Cavallaro and Greenstein, 2011 who concluded that angulated abutments had no effect on the implant or the prosthesis survival rate compared with straight abutments [24]. The current study's findings partially agree with 2019 research conducted by Goldberg et al. whom evaluated the removal torque values and abutment screws fracture strength with three abutment angulation groups (0°, 20°, and 28°). They concluded that the RTV was highest in the 0° group and lowest in the 28° group. Despite the fact that the groups were not statistically different, the authors contended that higher abutment angulations resulted in higher tensile forces to the screw [26].

In 2020, Opler et al [27] , attached angulated abutments to implant fixtures and clamped them to the manufacturer's recommended torque. They were then examined at two different angles, 0 and 28 degrees off-axial and significant differences in reverse torque mean values were discovered between the abutment-implant connections at both angles. Torque values were significantly decreased for 28-degree angulation. Different angulations were found to have an effect on screw torque and final preload. Screw joint stability may be compromised at extreme angulations greater than 15 degrees, which may have clinical implications, particularly in areas with excessive occlusal load [27].

More research is required to assess different angled screw systems from different manufacturers in imitation of different clinical situations in order to evaluate removal torque values and screw joint stability.

CONCLUSIONS

Based on the results of this study, it was concluded that:

1- The performance of angled abutments in regards to screw joint stability is less than that of straight abutments.

2- Dynamic cyclic loading and thermocycling aging had a significant effect on removal torque values of implant multi-unit abutments with 17 degree abutment angulation showing the greatest screw loosening potential.

Conflict of Interest

"The authors declare no conflicts of interests."

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