Torque Maintenance of Screw-Retained Implant-Supported Anterior Fixed Dental Prosthesis with Different Abutment Angulations After Aging

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Purpose: To assess the impact of abutment angulation on loosening torque, torque loss, and percentage of torque loss in the prosthesis and abutment screws after aging of the implant-supported prosthesis. **Materials and Methods:** Fifty epoxy maxillary casts with missing central, lateral, and canine teeth were used, and each cast received two implants. All casts were divided into five groups (n = 10): *(1)* both implants received straight abutments (0-0); *(2)* the central implant received a straight abutment and the canine implant received a 17.5-degree angled abutment (0-17.5); *(3)* the central implant received a straight abutment and the canine implant received a 35-degree angled abutment (0-35); *(4)* both implants received 17.5-degree angled abutments (17.5-17.5); and *(5)* both implants received 35-degree angled abutments (35-35). For each cast, a three-unit zirconia restoration was fabricated, and a torque meter was utilized to tighten the abutment screw (25 Ncm) and prosthesis screw (18 Ncm). The reverse torque value was recorded for each screw. All restorations were subjected to 3,500 thermal cycles between 5°C and 55°C and load cycled for 150,000 cycles with 50-N load. After the loosening torque was measured for each screw, the torque loss and percentage of torque loss were calculated. **Results:** There was a statistically significant difference in the torque loss of the central prosthesis screw ($P < .001$) and canine prosthesis screw ($P < .001$) between study groups. The 35-35 group showed the highest percentage of torque loss, while the 0–0 group showed the lowest value. A significant difference was found regarding the torque loss of the central abutment screw ($P < .001$) and canine abutment screw ($P < .001$). The abutment screws of the 35-35 group showed the highest percentage of torque loss, while the 0-0 groups showed the lowest percentage of torque loss. **Conclusion:** Screw loosening of the prosthesis and abutment screws increases with increasing abutment angulation after aging. In the same fixed prosthesis, the torque loss in the prosthesis and abutment screws was higher in canine screws employing different angled abutments. *Int J Oral Maxillofac Implants 2021;36:723–729. doi: 10.11607/jomi.8647*

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Selection of an appropriate implant abutment is important for the achievement of an esthetically pleasing and mechanically sound implant-supported prosthesis.[1,2] The concept of cement-retained restorations evolved in order to handle the esthetic and functional prerequisites of screw-retained restorations as well as the issue of less-optimal implant angulation.[3] However, the removal of excess cement represents a challenge while dealing with an implant-supported restoration employing the cement-retained concept.[4] Previous studies reported that failure to remove excess cement has a major contribution in the development of peri-implant diseases.[4,5] The concept of screw retention offers advantages such as better control of oral hygiene and retrievability, as the restoration can be easily repaired in case of fractures.[5]

Some implant manufacturers provide prefabricated abutments with advantages such as simplicity, cost-effectiveness, and time saving regarding the selection and ordering of the components.[6,7] Certain anatomical limitations such as bone concavities or bone resorption could necessitate surgical insertion of the implant in an angled direction, which could be corrected with angled abutments to preserve the arch integrity and the masticatory efficiency.[8] Additional benefits of using angled abutments include facilitating the paralleling of non-aligned implants, time saving, and eliminating the need for a bone augmentation procedure.[9–11] Therefore, the application of angled abutments in the anterior maxilla could be employed in certain clinical situations.[12–15]

The loosening of the abutment or prosthesis screws is among the mechanical complications within implant-supported restorations.[16–18] The prevalence of screw loosening currently varies from 7% to 39%.[19] The

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Fig 1 The screw-retained multiunit abutments attached with their corresponding implants: *(a)* both are straight abutments; *(b)* one is straight, and one is an angulated abutment; and *(c)* both are angulated abutments.

problem of screw loosening has been reported to be influenced by the type of implant-abutment interface, screw material, friction coefficient, restoration design, occlusal table, and implant diameter and number.[20–23] The loosening of the abutment or prosthesis screws can induce problems, such as disturbance in transfer and distribution of applied occlusal forces, fracturing of the screw or implant, and microgap formation at the implant-abutment interface, which allows bacterial leakage with subsequent effects on the osseointegration.[24,25] A number of causes can be related to screw loosening, such as improper implant positioning, inadequate tightening of the screw, excessive mechanical loading, and temperature variations in the oral environment.[26–28]

Loosening torque has been employed to evaluate joint stability in implant-supported restorations.[4,29,30] Different studies showed that the loosening torque decreased after cyclic loading, but other studies reported higher loosening torque.[31–35] Kim and Shin[28] found that after dynamic loading, the type of abutment did not have a major effect on screw loosening. Another study after cyclic loading studied screw loosening with prefabricated and custom abutments and found good joint stability.[36]

The purpose of the present study was to assess the impact of abutment angulation on torque maintenance of prosthetic and abutment screws after aging of screw-retained implant-supported anterior fixed dental prostheses. The null hypothesis was that there was an effect of abutment angulation on the torque maintenance of the prosthesis and abutment screws for screw-retained implant-supported anterior fixed dental prostheses.

MATERIALS AND METHODS

The central, lateral, and canine teeth were removed from a typodont maxillary cast (Pro2001-UL-SPFEM-32 typodont model, Nissan Dental Products) to mimic missed maxillary central, lateral, and canine teeth. The typodont maxillary cast was duplicated, and 50 casts were fabricated using epoxy resin material (Chema poxy150, CMB Chemicals). The duplicate epoxy casts

were divided into five groups (n = 10): *(1)* both central and canine implants received straight abutments (0-0); *(2)* the central implant received a straight abutment and the canine implant received a 17.5-degree angled abutment (0-17.5); *(3)* the central implant received a straight abutment and the canine implant received a 35-degree angled abutment (0-35); *(4)* both central and canine implants received 17.5-degree angled abutments (17.5-17.5); and *(5)* both central and canine implants received 35-degree angled abutments (35-35).

For proper placement of the implants in each group, a surgical guide was designed (Blue Sky Plan, BlueSky-Bio) and printed using a 3D printer (Shuffle XL, Phrozen tech). The osteotomy was prepared for each implant site with the aid of the surgical guide; then, each implant (4-mm diameter × 10-mm length Sky Implant, Bredent Medical) was placed in each corresponding site according to the manufacturer's instructions. An abutment for a screw-retained restoration (Sky Multi-unit Abutment, Bredent Medical), either straight or angled, was attached with each corresponding implant and tightened to the recommended torque of 25 Ncm (Fig 1).

Restoration Fabrication

Each epoxy cast with the abutments was sprayed with scan powder (Scanspray, Renfert) and scanned using a CAD/CAM scanner (Identica, Medit). A three-unit fixed partial denture was designed using CAD/CAM software (Exocad dental 2.2, Exocad): 1-mm wall thickness, 12-mm^2 connector dimension, 50-µm cement space, and 2.5-mm screw channel. The restorations were milled (Shera Eco-Mill, Shera) from the zirconia block (Super Translucent Multi-layered Katana Zirconia A2; Kuraray Nortake Dental), and sintered (SinterMax T1700, SinterMax) at 1,500°C, following the manufacturer's recommendations.

The fitting surface of the zirconia restorations and the bonding area of the titanium prosthesis caps (Sky Prosthetic cap, Bredent Medical) were airborne particle abraded with 50 µm alumina (Renfert) at 10-mm distance with 4-bar pressure for the zirconia restoration, and 6-bar pressure for the titanium cap. All zirconia restorations and prosthesis caps were cleaned

Fig 2 *(a)* Four-station load cycling machine with specimens in position; *(b)* the specimen positioned and secured with custom-made positioning device; and *(c)* specimens mounted inside the chamber during load application.

ultrasonically for 10 minutes and air-dried. The inner surfaces of the zirconia restorations and the bonding area of the prosthesis caps were primed (MKZ Primer, Bredent Medical). The resin cement (DTK Adhesive, Bredent Medical) was mixed and applied into the fitting surface of the zirconia restoration and the bonding area of the prosthesis cap, following the manufacturer's recommendations. Each restoration was adhesively bonded to its respective prosthesis caps using resin cement (DTK Adhesive, Bredent Medical), following the manufacturer's instructions. All restorations were kept in distilled water for 3 days to ensure proper setting of the resin cement.

Each specimen was stabilized by a bench vice (as a holding device) during the testing procedure to establish firm stabilization and inhibit movements of the specimen during capturing of the torque measurements to ensure application of precise and reproducible torque with each screw.[37] A digital torque meter device (TSD-50 Torque Screw Driver, Electromatic Equipment) was used to tighten the abutment screw (25 Ncm) and the prosthesis screw (18 Ncm) as instructed by the manufacturer, for 5 seconds.[38] The torque meter device was held steady and cautiously aligned with the driver seated in the screw head, kept with the longitudinal axis of the abutment, and turned clockwise until the screw was tightened to the prescribed torque.[37] After 10 minutes, each screw was retightened in order to minimize the settling effect.[39] After a further 10 minutes, the reverse torque value was recorded for each screw by rotation in an counterclockwise direction using the same torque meter device as described previously. Then, the screw was retightened to the prescribed torque.[37] The screw access channels were sealed (Filtek Z250, 3M ESPE). Then, immediately, the specimens were subjected to aging procedures.

Aging

To simulate the intraoral conditions, all restorations were thermal aged (SD Mechatronic Thermocycler) in water for 3,500 thermal cycles (equivalent to 1 year) between 5°C and 55°C with a dwelling time of 30 seconds.[40] Additionally, cyclic loading was performed for all specimens using a four-station dynamic loading cycler (Model ACH-09075DC-T, AD-Tech Technology Co; Fig 2). Each compartment has an upper Jackob's chuck as a hardened steel antagonist holder that can be secured with a screw and a lower plastic sample holder in which the specimen can be fixed. Each specimen was placed and secured in a custom-made positioning Teflon holder at 45 degrees. The specimens were loaded with 49 N (5 kg) at a rate of 1.6 Hz for 150,000 cycles to simulate 1 year of masticatory forces in the anterior dentition.[41,42] The applied load was exerted on the cingulum of the pontic (3 mm below the incisal edge) via a 5.4-mm steel piston at a descending speed of 40 mm/sec.[41,43,44]

Torque Loss

Following thermal aging and cyclic loading, the loosening torque was determined in a counterclockwise motion utilizing the torque meter device as described previously; then, the torque loss and percentage of torque loss were calculated.

Statistical Analysis

The data were statistically resolved using the Statistical Package for Social Science (SPSS). The Shapiro-Wilk test was used to evaluate data for determination of normality and equality of variance. To compare data, one-way analysis of variance (ANOVA) followed by the post hoc Tukey test was used. The level of statistical significance was set at $P \le .05$.

Table 1 Mean ± SD Values of the Loosening Torque (Ncm), Torque Loss (Ncm), and Percentage of Torque Loss (%) Regarding Prosthesis Retaining Screw of the Tested Groups After Aging

		0-0 Mean ± SD	0-17.5 Mean ± SD	17.5-17.5 Mean ± SD	0-35 Mean ± SD	35-35 Mean ± SD	P
Loosening torque	Central	15.7 ± 1[c]	15.8 ± 0.3[a,d]	14.9 ± 0.5[a,e]	15.3 ± 0.9[f]	13.7 ± 0.4[c,d,e,f]	< .001
	Canine	15.5 ± 1[1,4]	15.2 ± 0.4[2,5]	14.8 ± 0.5[3,6]	13.1 ± 0.4[1,2,3]	13.3 ± 0.4[4,5,6]	< .001
	P	.395	.003	.661	< .001	.001	
	Average	15.6 ± 0.9	15.4 ± 0.2	14.8 ± 0.3	14.2 ± 0.5	13.5 ± 0.3	< .001
Torque loss	Central	2.3 ± 1[g]	2.2 ± 0.3[h]	3.0 ± 0.7[i]	2.7 ± 0.9[j]	4.4 ± 0.3[g,h,i,j]	< .001
	Canine	2.6 ± 0.9[7,10]	2.7 ± 0.4[8,11]	3.2 ± 0.6[9,12]	4.9 ± 0.4[7,8,9]	4.7 ± 0.4[10,11,12]	< .001
	P	.108	.003	.333	< .001	.001	
	Average	2.4 ± 0.9	2.4 ± 0.2	3.1 ± 0.5	3.7 ± 0.5	4.4 ± 0.3	< .001
Percentage of torque loss	Central	12.8 ± 5.6[k]	12.3 ± 1.5[l]	16.7 ± 3.6[m]	15.0 ± 5.1[n]	24.9 ± 2.1[k,l,m,n]	< .001
	Canine	14.3 ± 5.2[13,16]	15.2 ± 2.1[14,17]	17.8 ± 3.2[15,18]	27.1 ± 2.0[13,14,15]	26.1 ± 2.3[16,17,18]	< .001
	P	.108	.003	.396	< .001	.001	
	Average	13.6 ± 5.3	13.7 ± 1.4	17.2 ± 2.8	21.0 ± 3.0	24.9 ± 2.1	< .001

SD = standard deviation; P significant at < .5.
Uppercase similar letters or numbers denote significant difference.
0-0 = both implants were 0-degree angulated; 0-17.5 = central implant was 0-degree angulated and canine implant was 17.5-degree angulated; 0-35 = central implant was 0-degree angulated and canine implant was 35-degree angulated; 17.5-17.5 = both implants were 17.5-degree angulated; 35-35 = both implants were 35-degree angulated.
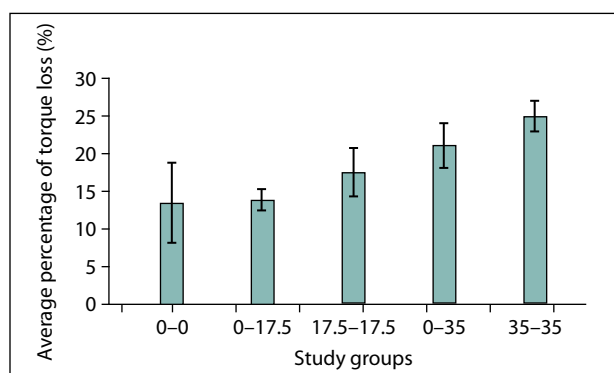

Fig 3 Average percentage of torque loss (%) in the study groups regarding the prosthesis screw.

RESULTS

Prosthesis Screw (Table 1)

The one-way ANOVA test revealed a significant difference in the loosening torque of the central prosthesis screw (df = 4, F = 13.95, P < .001) and canine prosthesis screw (df = 4, F = 33.43, P < .001). Also, a significant difference was found in the torque loss of the central prosthesis screw (df = 4, F = 13.10, P < .001) and canine prosthesis screw (df = 4, F = 35.21, P < .001). The prosthesis screws of the 35-35 group showed the highest average percentage of torque loss (24.9% ± 2.1%) followed by the prosthesis screws of the 0-35 group (21.1% ± 3.1%), while the 0-0 group showed the lowest average percentage of torque loss (13.6% ± 5.3%; Fig 3).

Abutment Screw (Table 2)

The one-way ANOVA test revealed a significant difference in the loosening torque of the central abutment screw (df = 4, F = 7.13, P < .001) and canine prosthetic screw (df = 4, F = 10.44, P < .001). Also, a significant difference was found in the torque loss of the central abutment screw (df = 4, F = 6.26, P < .001) and canine abutment screw (df = 4, F = 9.58, P < .001). The abutment screws of the 35-35 group showed the highest average percentage of torque loss (19.15% ± 3.3%) followed by the abutment screws of the 0-35 group (16.0% ± 4.8%), while the 0-0 group showed the lowest average percentage of torque loss (11.4% ± 1.4%; Fig 4).

DISCUSSION

The objective of the present study was to assess and compare the impact of abutment angulations on the torque maintenance of prosthesis and abutment screws with screw-retained implant-supported zirconia fixed dental prostheses. The null hypothesis regarding torque maintenance was confirmed because there was a considerable variation regarding the loosening torque, torque loss, and percentage of torque loss.

The method of retention between the prosthetic parts either using the prosthesis retaining screw or cementation is a major concern with implant-supported restorations.[6] In the present study, 25 Ncm and 18 Ncm was applied (according to the manufacturer's instructions) as the tightening torque for the abutment and

Table 2 Mean ± SD Values of the Loosening Torque (Ncm), Torque Loss (Ncm), and Percentage of Torque Loss (%) Regarding Abutment Screw of the Tested Groups After Aging

|		0-0 Mean ± SD	0-17.5 Mean ± SD	17.5-17.5 Mean ± SD	0-35 Mean ± SD	35-35 Mean ± SD	P
Loosening torque	Central	22.2 ± 0.4[a]	22 ± 0.7[b]	21.3 ± 1.3	21.9 ± 1.3[c]	20.2 ± 0.8[a,b,c]	< .001
	Canine	22.1 ± 0.5[1,3]	21.1 ± 0.8	21.8 ± 0.8[2,4]	20 ± 1.1[1,2]	20.3 ± 1[3,4]	< .001
	P	.389	.016	.310	< .001	.705	
	Average	22.1 ± 0.3	21.5 ± 0.5	21.5 ± 0.8	20.9 ± 1.1	20.2 ± 0.6	< .001
Torque loss	Central	2.8 ± 0.4[d]	3.0 ± 0.7[e]	3.7 ± 1.3	3.1 ± 1.3[f]	4.7 ± 1.0[d,e,f]	< .001
	Canine	2.9 ± 0.5[5,7]	3.8 ± 0.9	3.3 ± 0.8[6,8]	4.9 ± 1.3[5,6]	4.8 ± 1[7,8]	< .001
	P	.414	.026	.329	< .001	.773	
	Average	2.8 ± 0.3	3.3 ± 0.6	3.4 ± 0.8	4.0 ± 1.2	4.7 ± 0.8	< .001
Percentage of torque loss	Central	11.1 ± 1.5[g]	11.8 ± 2.7[h]	14.8 ± 5.2	12.5 ± 5.2[i]	18.9 ± 3.9[g,h,i]	< .001
	Canine	11.6 ± 1.9[9,11]	15.1 ± 3.4	13.1 ± 3.1[10,12]	19.5 ± 5[9,10]	19.3 ± 3.9[11,12]	< .001
	P	.414	.026	.329	< .001	.745	
	Average	11.4 ± 1.4	13.4 ± 2.4	13.9 ± 3.3	16.0 ± 4.8	19.1 ± 3.3	< .001

SD = standard deviation; *P* significant at <.5.
Uppercase similar letters or numbers denote significant difference.
0-0 = both implants were 0-degree angulated; 0-17.5 = central implant was 0-degree angulated and canine implant was 17.5-degree angulated; 0-35 = central implant was 0-degree angulated and canine implant was 35-degree angulated; 17.5-17.5 = both implants were 17.5-degree angulated; 35-35 = both implants were 35-degree angulated.

prosthesis-retaining screws, respectively. Additionally, the screws were retightened after 10 minutes to compensate for the settling effect.[37] The loosening torque is predicted to be the same as tightening torque at perfect connections.[4] Nevertheless, it is difficult to achieve according to several studies with reported torque loss up to 39% depending on the implant system.[4,16,17,19] The present study revealed that the torque loss value for both the prosthesis-retaining screw and abutment-retaining screw of the studied restorations was lower than the initial tightening torque. This finding supports the results of other studies.[30] In the present study, the loosening torque was evaluated after aging. Sahin and Ayyildiz evaluated the association between loosening torque and microleakage and concluded that microleakage affects torque maintenance.[24] Additionally, screw loosening was associated with micromovements at the implant-abutment interface when the screw was exposed to external loads with resulting elevation in the torque loss.[36] However, it was reported that the implant numbers have an effective role in minimizing the incidence torque loss.[20]

The problem of screw loosening is multifactorial, induced by many causes such as the implant-abutment interface, screw design and material, passivity, abutment design, and occlusal loads.[4] In the present study, restorations with angled abutments demonstrated elevated torque loss compared with restorations with straight abutments. This could be related to the direction of compressive axial load and the resultant off-axis forces, with the angulated abutments, causing tension
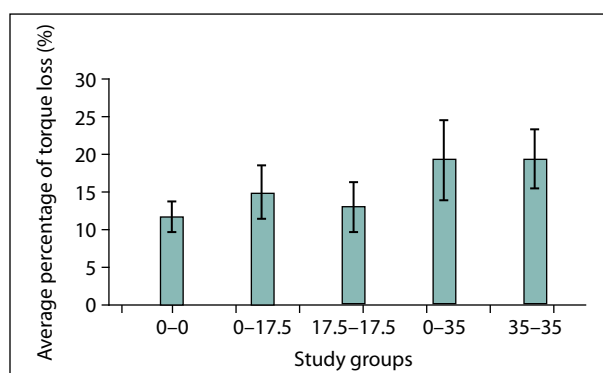
Fig 4 Average percentage of torque loss (%) in the study groups regarding the abutment screw.

to the screw and affecting the preload maintenance with such unfavorable loading conditions.[10,11] The greater the abutment angulation, the greater the angular forces that affect the implant-supported restoration, especially the screws.[12] Also, the angular forces may create and magnify torsional forces, which add more risk to torque maintenance.[8] El-Sheikh et al[25] studied the effect of abutment angulation on torque loss after dynamic loading and concluded that with increasing abutment angulations, screw loosening increases. However, the eccentric loading would not necessarily cause more torque loss as opposed to centric loading.[33] Kim and Shin[28] investigated the influence of dynamic loading on the loosening torque and found the initial screw loosening of CAD/CAM abutments, but it did not

influence the prefabricated and cast abutments. Benjaboonyazit et al[30] studied the loosening torque under various load cycle numbers and concluded that the loosening torque decreased significantly after 50,000 load cycles but did not show significant change until 2,000,000 load cycles.

The published studies showed a reduction in the percentage of torque loss up to 10% of the initial tightening torque.[23] The settling effect could clarify these results.[16,18] The tightening torque is required to overcome the friction of the mating surfaces at the implant-abutment interface. Additionally, the wear at the mating surfaces can cause micromovements, which can affect the elongated screw and cause preload loss.[18] The mechanical cyclic loading can induce micromovements and friction in between the screw and the implant, causing reduction in clamping force with a subsequent decrease in the preload.[1] Scherg and Karl[2] studied the loosening torque in implant-supported fixed partial dentures and found that the prosthesis-retaining screws lost 20% of the initial tightening torque after cyclic loading. More torque loss percentages related to angled abutments were also revealed in the results of the present study. These results are in line with other studies that have shown greater joint stability with straight abutments.[15,32,34,36]

The limitations of the present study include the effect of temperature and load cycles needing to be studied individually and the short-term loading period with only one implant system. Thus, longer evaluation periods and more implant systems will be needed in further studies.

CONCLUSIONS

The following conclusions were drawn based on the results from this in vitro study: (1) the screw loosening of the prosthesis and abutment screws increases with increasing abutment angulation after thermal and dynamic cyclic aging; and (2) in the same fixed prosthesis, the torque loss in prosthesis and abutment screws was higher in canine screws employing different angled abutments after thermal and dynamic cyclic aging.

ACKNOWLEDGMENTS

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