Effect of Repeated Screw Joint Closing and Opening Cycles and Cyclic Loading on Abutment Screw Removal Torque and Screw Thread Morphology: Scanning Electron Microscopy Evaluation

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Purpose: *To evaluate the effect of repeated screw joint closing and opening cycles and cyclic loading on abutment screw removal torque and screw thread morphology using scanning electron microscopy (SEM).* ***Materials and Methods:*** *Three groups (n = 10 in each group) of implant-abutment-abutment screw assemblies were created. There were also 10 extra abutment screws as new screws in group 3. The abutment screws were tightened to 12 Ncm with an electronic torque meter; then they were removed and removal torque values were recorded. This sequence was repeated 5 times for group 1 and 15 times for groups 2 and 3. The same screws in groups 1 and 2 and the new screws in group 3 were then tightened to 12 Ncm; this was also followed by screw tightening to 30 Ncm and retightening to 30 Ncm 15 minutes later. Removal torque measurements were performed after screws were subjected to cyclic loading (0.5×10^6 cycles; 1 Hz; 75 N). Moreover, the surface topography of one screw from each group before and after cyclic loading was evaluated with SEM and compared with an unused screw.* ***Results:*** *All groups exhibited reduced removal torque values in comparison to insertion torque in each cycle. However, there was a steady trend of torque loss in each group. A comparison of the last cycle of the groups before loading showed significantly greater torque loss value in the 15th cycle of groups 2 and 3 compared with the 5th cycle of group 1 ($P < .05$). Nonetheless, torque loss values after loading were not shown to be significantly different from each other.* ***Conclusion:*** *Using a new screw could not significantly increase the value of removal torque. It was concluded that restricting the amount of screw tightening is more important than replacing the screw with a new one when an abutment is definitively placed.*

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Acceptable screw retention of the abutment to the implant is required for the overall success of an implant-supported prosthesis. Regardless of the implant system or type of restoration, retention is dependent on screw preload, which is the tensile force generated in the shank and threads of the screw when a torquing force is applied.[1] The abutment screw can be considered as a spring; it elongates when insertion torque is applied. As it tends to return to its original length, a clamping force is created, which unites the abutment to the implant.[2–4] Indeed, preload creates a strong compressive clamping force, which keeps the mating components firmly connected.[3,5] The preload and clamping force are quantitatively equal but in opposite directions.

Screw loosening or screw fracture is considered one of the most common complications for implant-supported prostheses[6–8]; thus, retorquing is required in the first year.[9,10] Screw joint instability could result in unfavorable consequences such as failure of other components, overloading of adjacent implants, biologic complications resulting from a microgap,[7,11–15] patient and practitioner inconvenience, and extra

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financial burden when it happens frequently.[16] This emphasizes the importance of developing a clinically effective clamping force through screw preload as a main factor for implant-supported prosthesis success.

The amount of preload generated at the threads of a screw depends on many factors, such as tightening torque, mating component material,[1,2] mating surface microroughness, the presence and type of lubricant, settling of the screw after initial torque,[2] and the screw head design[1] regardless of veneering material[17] and abutment type.[11,17]

The engineering literature declares that the relationship between torque and preload is not linear, but involves another factor named friction. Each time a tightening torque is applied, a portion of energy is used against the frictional resistance by flattening surface irregularities so the preload is reduced. This relationship can be described with the following formula[18]:

$$\mathrm{T}_f = \frac{\mathrm{F}_f}{2}\left(\frac{\tan\beta + \mu_s/cos\alpha_n}{1 - \mu_s \tan\beta/cos\alpha_n}\, d_2 + \mu_w D_w\right)$$

$$^{*}\tan\beta = P/(\pi d_2)$$

where

T_f = applied torque
F_f = fastener preload or tension
β = lead angle of the thread
μ_s = coefficient of the friction in threads
d_2 = effective diameter of the thread
α_n = flank angle at normal section to the thread
μ_w = coefficient of friction under the head
D_w = effective diameter of the head contact
P = thread pitch

The equation above is usually interpreted by the simple short form equation using torque coefficient or nut factor, K.[18] The nut factor summarizes all of the known variables that influence the torque-tension relationship:

$T_f = KF_f\, d$
T_f = applied torque
K = nut factor
F_f = fastener preload or tension
d = diameter of the thread

Therefore, any factor that decreases the friction, such as repeated removal and retorquing, as well as the use of lubricants leads to increased preload.[3,18,19] However, some investigators believe that closing and opening the screw repeatedly could decrease the amount of preload.[11]

The following formula shows the relation between preload and removal torque[18]:

$$|\mathrm{T}_f| = \frac{\mathrm{F}_f}{2}\left(\frac{-\tan\beta + \mu_s/cos\alpha_n}{1 + \mu_s \tan\beta/cos\alpha_n}\, d_2 + \mu_w D_w\right)$$

According to the formula, in an implant-abutment assembly, the resistance to opening torque is in direct proportion to the tension in the screw and the frictional resistance of the mating components. Thus, preload maintenance mainly depends on component friction.[13]

Although repeated screw joint closing and opening cycles and the resulting flattened irregularities increase the preload by saving more energy,[19] they can decrease frictional resistance to screw joint opening when functional forces exceed preload.[13] With decreased friction, preload may not be easily maintained.

In implant-level impression making, as the abutment screw is serially closed and opened before definitive restoration insertion, there is always a concern of screw loosening. Moreover, this concern is accentuated by possible clinical and laboratory errors that increase the closing/opening cycles. However, there is not clear information to prove whether or not a new screw can better maintain the preload. In some studies,[11,13] the number of torque cycles and amount of torque do not simulate the condition that actually occurs. For instance, the screws are tightened many times, each time with the torque recommended for the definitive prosthesis insertion appointment,[13] while except for the final torque, the screws should only be finger tightened. In the present study, the authors have tried to better simulate the real procedure.

In the literature, the effect of consecutive closing and opening of the screws on the resistance to loosening is still controversial. Haack et al[3] reported that successive loosening and retightening would lead to progressive increase in preload. Tzenakis et al[19] also declared that using a gold prosthetic screw from the try-in appointment might result in obtaining optimal preload during final torquing at the insertion appointment. Byrne et al[11] found a reduction in preload after repeated closing and opening cycles. Weiss et al[13] and Kim et al[20] recommended avoiding repeated closing/opening unnecessarily. Some investigators[21,22] have evaluated the influence of using a new screw after multiple screw insertion cycles. Cardoso et al[21] stated that replacing the screw with a new one after 10 cycles could not increase resistance to loosening. In contrast, Guzaitis et al[22] noted that after 10 screw insertion cycles, a new screw should be used to maximize screw removal torque.

The purpose of this in vitro study was to evaluate the effect of repeated abutment screw joint closing and opening cycles and cyclic loading on removal torque value (RTV) and screw thread morphology using scanning electron microscopy (SEM), and also to determine the impact of using a new screw. The null

Table 1 Materials Used

Component	Quantity	Size
Superline implant	30	Implant platform diameter: 4.0 mm; Implant body diameter: 3.8 mm; Implant bevel height: 0.2 mm; Length: 12 mm
Dual abutment	30	Diameter: 4.5 mm; G/H: 3.5 mm; Conical hex connection
Abutment screw	40	

G/H = gingival height.

Fig 1 Implant, abutment, and abutment screw used in this study.

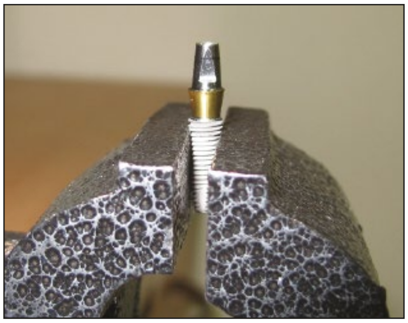

Fig 2 Mounting jig that tightly holds implant.

Fig 3 Torque application with electronic torque meter.

hypotheses were that RTV and screw thread morphology would not be significantly affected by multiple screw joint closing and opening cycles and cyclic loadings and that there is no need to use a new screw.

MATERIALS AND METHODS

Thirty implants (Superline, Dentium) measuring 4 mm in platform diameter and 12 mm in length; 30 straight abutments (Dual abutment, Dentium) measuring 4.5 mm in diameter, 5.5 mm in length, and 3.5 mm in gingival height; and 40 titanium abutment screws were used (Fig 1 and Table 1). Before any insertion/removal (I/R) cycles, one screw was qualitatively assessed with SEM. Then, the samples were randomly divided into three groups. Each group included 10 implants, 10 straight abutments, and 10 primary abutment screws ($n = 10$). The last group included 10 extra abutment screws as new screws. To simulate the oral cavity environment, before inserting the screw into the implant, 1 mL of normal saline was applied to the internal threads of the implant using an insulin syringe. Each implant was mounted in a mounting jig (Fig 2); then, the corresponding abutment was secured to it by each primary abutment screw and torqued to 12 Ncm using an electronic torque meter (Lutron Electronic Enterprise) (Fig 3). To achieve valid and reliable measurements, the electronic torque meter was first calibrated. Tightening to 12 Ncm is assumed to be almost equal to manually closing the screw. Dellinges and Tebrock[23] showed that the mean torque value obtained with handheld drivers was 11.55 Ncm. Five minutes later, the RTV was measured using the same electronic torque meter and recorded. In group 1, the mentioned procedure was done five times. In this group, opening/closing cycles simulated the steps of the prosthetic procedure until the definitive prosthesis insertion appointment. In groups 2 and 3, samples were subjected to 10 extra 12-Ncm torque cycles to simulate conditions in which the process is repeated because of the possible clinical and laboratory errors. At this step, one screw was randomly selected from each group to be assessed under SEM. Afterward, the same screws in group 1 were tightened to 12 Ncm for the 6th time and in group 2 for the 16th time. In group 3, the primary screws were replaced with the new ones to be tightened to 12 Ncm. They were all torqued and 15 minutes later retorqued to 30 Ncm as recommended by the manufacturer for the definitive prosthesis insertion appointment. Embedment relaxation occurs due to microroughness existing on the mating surfaces; when the initial tightening torque is applied to the screw, only the prominent spots will be in contact, so with embedment relaxation that flattens the prominent spots under load,

Table 2 Test Groups and Conditions

	Group 1	Group 2	Group 3			
Step	PS	PS	PS	NS	No. of torque cycles/ amount of torque	Equivalent step
1	×	×	×		1/12 Ncm	Metal framework fabrication
2	×	×	×		1/12 Ncm	Metal framework try-in
3	×	×	×		1/12 Ncm	Porcelain build-up
4	×	×	×		1/12 Ncm	Occlusal adjustment
5	×	×	×		1/12 Ncm	Porcelain glazing
6		×	×		10/12 Ncm	10 extra possible errors
7				×		Using a new abutment screw
8	×	×		×	1/12 Ncm + 2/30 Ncm	Definitive prosthesis insertion
9	×	×		×		6 months use (cyclic loading)

PS = primary screw; NS = new screw.

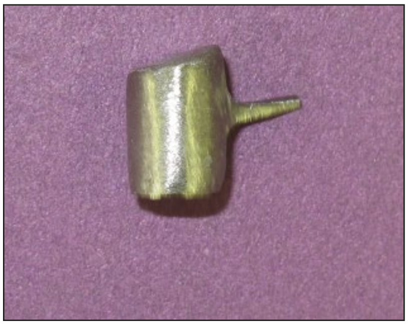

Fig 4 *(Left)* Metal crown with 45-degree inclination in occlusal surface and a horizontal process.

Fig 5 *(Right)* Cyclic loading machine.

2% to 10% of the initial preload is lost.[24] To limit this process, retightening after 10 to 15 minutes is recommended.[25] The number of torque cycles and amount of torque for each group are described in Table 2. To better simulate masticatory loads, designing of a crown for the abutment was needed, so crowns from base metal alloy (Wirobond C, Bego) at an angle of 45 degrees were fabricated (Fig 4). Crowns were formed similarly and had a horizontal process for easy removal after the cyclic load process.[26] There was no need to temporarily cement the crowns because they were stable enough.

Then, all the specimens were subjected to cyclic loading of 75 N for 500,000 cycles at 1 Hz frequency, which simulates the mastication load at 6 months[27] (Fig 5). Finally, the RTVs were recorded with the electronic torque meter. Also, the same selected screws were again assessed under SEM.

Cyclic Loading

To apply the load along the long axis of the abutment and implant, the specimens were vertically placed in the molds using a surveyor. At this stage, the autopolymerizing acrylic resin (Repair & Pour Resin, Medidentco) was poured into the molds up to 1 mm below the connection. After final setting, the acrylic resin blocks were mounted inside the cyclic loading device (Chewing simulator, S-D mechatronic). Finally, the specimens were subjected to cyclic loading of 75 N for 500,000 cycles at 1 Hz.

Scanning Electron Microscope

One screw from each group was randomly selected. Before taking photomicrographs, they were cleansed with an ultrasonic cleaner for 5 minutes.[20] The screws were affixed to mounting plates with a carbon tape. The images of the threaded part were taken at magnifications of ×40, ×200, and ×500. Then, the screw crest, root, and slope of the thread were assessed in more detail at ×1,000 magnification. To evaluate the changes of the screw head, photomicrographs were taken at ×50 and at ×500 magnification. The surface morphology and the quality of surface characteristics of the screw threads according to roughness and porosity were evaluated.

Statistical Analysis

The percentage values of torque loss in relation to the insertion torque were calculated using this formula: (insertion torque – removal torque) × 100/insertion torque.

Data were analyzed with repeated measures analysis of variance (ANOVA), one-way ANOVA, and

Table 3 Descriptive Measurements of Torque Loss in Group 1

	Minimum		Maximum		Mean		SD	
Cycle	Ncm	%	Ncm	%	Ncm	%	Ncm	%
1	4	33.33	9	75	6.9	57.5	1.66	13.83
2	1	8.33	9	75	5.2	43.33	2.57	21.41
3	–2	–16.66	8	66.66	5.5	45.83	3.24	27
4	4	33.33	9	75	7.1	59.16	1.91	15.91
5	2	16.66	9	75	6.4	53.33	2.06	17.16

Table 4 Descriptive Measurements of Torque Loss in Group 2

	Minimum		Maximum		Mean		SD	
Cycle	Ncm	%	Ncm	%	Ncm	%	Ncm	%
1	4	33.33	10	83.33	7.4	61.66	1.64	13.66
2	3	25	10	83.33	7.5	62.5	2.17	18.08
3	3	25	11	91.66	8.7	72.5	2.35	19.58
4	4	33.33	11	91.66	8.9	74.16	1.91	15.91
5	0	0	11	91.66	7.2	60	3.58	29.83
6	–1	–8.33	11	91.66	7.6	63.33	3.74	31.16
7	1	8.33	10	83.33	7.7	64.16	2.75	22.91
8	5	41.66	11	91.66	9.3	77.5	2.21	18.41
9	3	25	11	91.66	8	66.66	2.21	18.41
10	8	66.66	11	91.66	9.1	75.83	0.87	7.25
11	5	41.66	10	83.33	7.9	65.83	1.79	14.91
12	2	16.66	11	91.66	7.4	61.66	2.87	23.91
13	7	58.33	11	91.66	8.9	74.16	1.59	13.25
14	8	66.66	11	91.66	9.8	81.66	1.03	8.58
15	8	66.66	11	91.66	9.1	75.83	0.99	8.25

Table 5 Descriptive Measurements of Torque Loss in Group 3

	Minimum		Maximum		Mean		SD	
Cycle	Ncm	%	Ncm	%	Ncm	%	Ncm	%
1	2	16.66	11	91.66	8.3	69.16	2.75	22.91
2	4	33.33	11	91.66	8.7	72.5	2.11	17.58
3	3	25	11	91.66	8	66.66	2.90	24.16
4	7	58.33	11	91.66	9.4	78.33	1.26	10.5
5	1	8.33	10	83.33	7.7	64.16	3.65	30.41
6	4	33.33	11	91.66	7.8	65	2.52	21
7	7	58.33	11	91.66	9	75	1.41	11.75
8	3	25	11	91.66	7.5	62.5	2.50	20.83
9	3	25	10	83.33	7.1	59.16	2.55	21.25
10	4	33.33	10	83.33	7.5	62.5	2.22	18.5
11	5	41.66	11	91.66	8	66.66	1.63	13.58
12	3	25	11	91.66	7.6	63.33	2.67	22.25
13	3	25	11	91.66	7.1	59.16	2.88	24
14	4	33.33	11	91.66	7.8	65	2.82	23.5
15	6	50	11	91.66	8.6	71.66	1.77	14.75

Tukey's honest significant difference (HSD) post hoc tests, using SPSS software for Windows. The data were statistically compared within and between groups. Differences were considered statistically significant at $P = .05$.

RESULTS

Maximums, minimums, means, and standard deviations for torque loss values are reported in Tables 3 to 5. There was a substantial amount of torque loss in

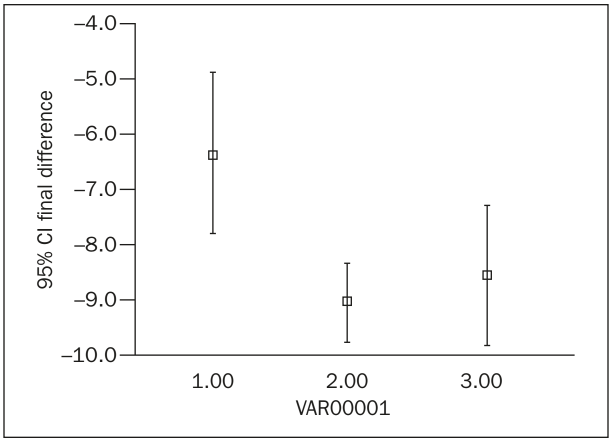

Fig 6 Mean error bar and 95% confidence interval of torque loss for the last I/R cycle before loading in each group.

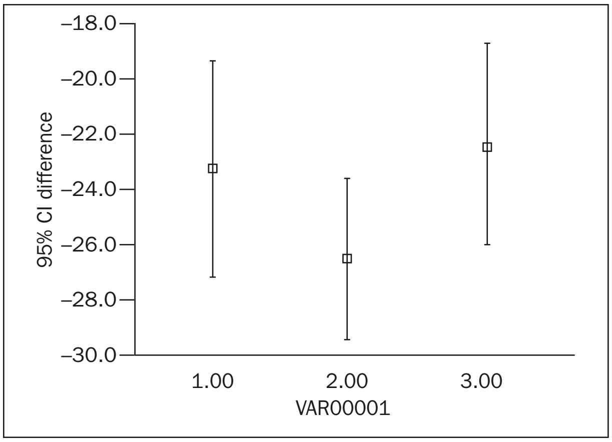

Fig 7 Mean error bar and 95% confidence interval of torque loss after loading in each group.

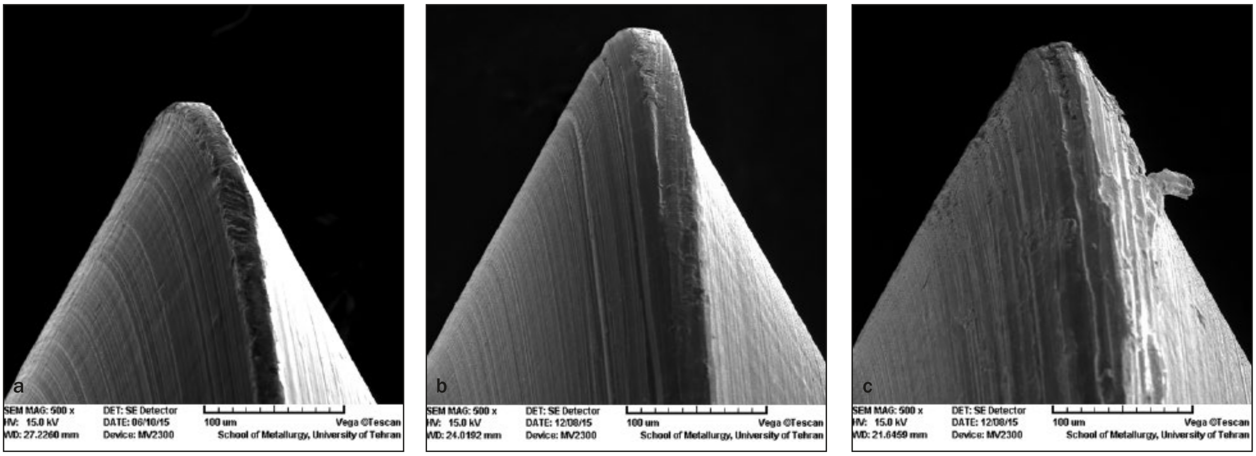

Fig 8 SEM micrographs (×500 magnification) of abutment screw threads before loading for *(a)* unused screw, *(b)* after five I/R cycles, and *(c)* after 15 I/R cycles.

each cycle of all three groups. Although repeated measures ANOVA showed a steady trend of torque loss in each group, one-way ANOVA revealed a significant difference among the last repetition of the groups before loading (Fig 6; $P < .05$). Tukey HSD post hoc analysis showed significantly greater torque loss value in the 15th cycle of groups 2 and 3 compared with the 5th cycle of group 1 ($P < .05$). Nonetheless, torque loss values after loading were not shown to be significantly different from each other (Fig 7).

SEM Findings

SEM micrographs of selected screws are presented in Figs 8 to 11. In general, it could be seen that even a precisely machined new screw was not highly smoothed. However, SEM micrographs after 5 I/R cycles indicated a smoother surface of the crests and disappearance of the nodules of the roots. In contrast, after 15 cycles, a kind of desquamation of the superficial layer was observed in some slope areas. Surface analysis of the screw head exhibited that the corner edge of the hexed slot was gradually rounded as the test proceeded. SEM analysis after loading also displayed more destruction of the thread surface. In addition, even on a new screw, some flakes that had possibly detached from the previous screw could be simply detected.

DISCUSSION

The aim of this study was to investigate if repeated screw joint closing and opening cycles will affect the abutment screw removal torque or not. The results found in this study indicate that the RTV was considerably lower than the insertion torque in all I/R cycles. However, it should be noted that evaluation of the removal torque of the screws does not consider the manner in which occlusal loads transfer to the interfaces between the implant, abutment, and screw in a clinical situation, and neglects that the antirotational feature

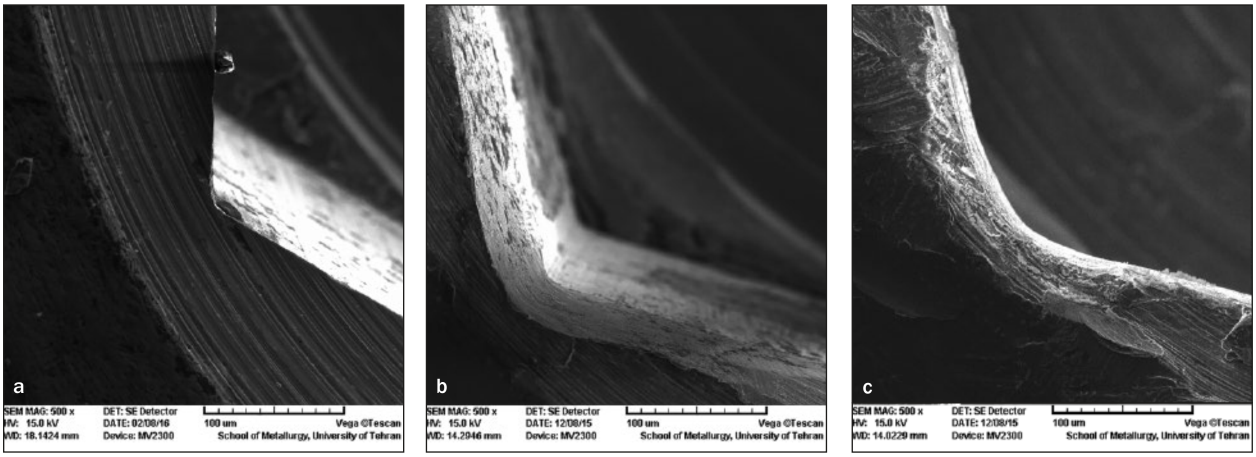

Fig 9 SEM micrographs (×500 magnification) of internal hexagonal slot of screw head before loading for *(a)* unused screw, *(b)* after five I/R cycles, and *(c)* after 15 I/R cycles.

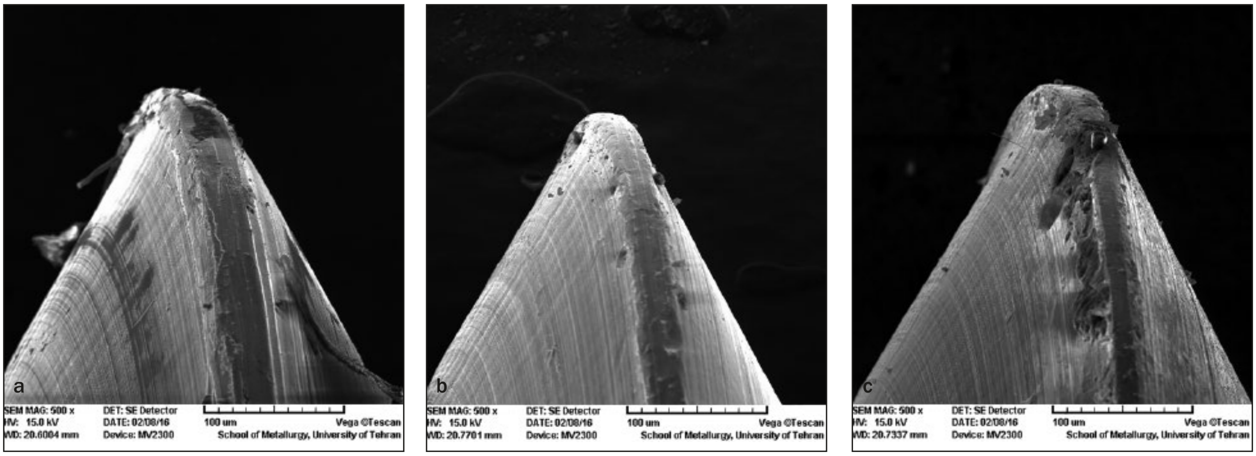

Fig 10 SEM micrographs (×500 magnification) of abutment screw threads after loading for *(a)* new screw, *(b)* after five I/R cycles, and *(c)* after 15 I/R cycles.

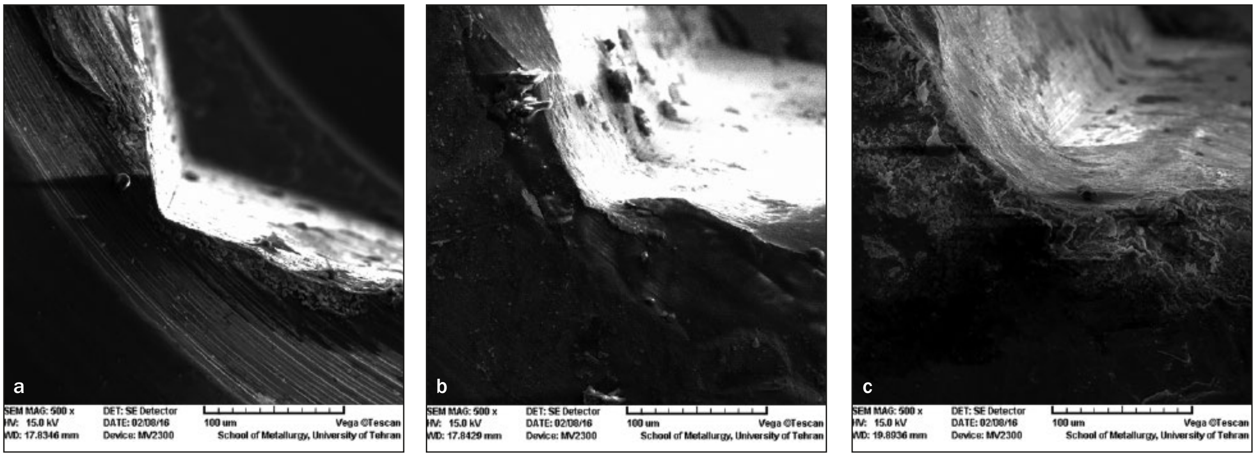

Fig 11 SEM micrographs (×500 magnification) of internal hexagonal slot of screw head after loading for *(a)* new screw, *(b)* after five I/R cycles, and *(c)* after 15 I/R cycles.

could possibly limit the role of the occlusal loads in the loosening of the screws.[28] However, the trend of the RTVs during repeated I/R cycles was steady in each group; the RTV of the last cycle before cyclic loading in groups 2 and 3 (15th cycle) was significantly lower than group 1 (5th cycle). This might be attributed to the gradual and inconspicuous changes of the values. Thus, it can be concluded that there is an inverse relationship between the numbers of I/R cycles of abutment screw and removal torque in the last cycles. In other words, increasing the times an abutment screw is closed and opened eventually will result in reducing the removal torque, and increasing the risk of screw loosening. The pretest SEM micrographs of the baseline screw displayed that even a precisely machined new surface is not highly smoothed. This observation is in agreement with that of Tzenakis et al[19] and Guzaitis et al.[22] Since neither the internal threads of the implant nor the screw threads can be machined highly smooth, there will always be high spots on the mating surfaces. Thus, when the initial torque is applied, high spots will be the only contacting surfaces that flatten under load. Consequently, some of the initial preload is lost.[24] This process is called settling or embedment relaxation. Greater microroughness and larger external loads tend to increase settling.[29] Hence, these surface irregularities reduce preload as well as the removal torque in initial cycles. Although due to a decrease in the coefficient of friction, an increase in preload and RTVs in subsequent cycles might be expected, in the present study, a steady and finally a declining trend of RTVs was encountered. This could be justified by SEM micrographs taken after 15 cycles, in which the authors observed that some of the threads suffered a kind of desquamation and the superficial layer was destroyed in some areas. These destroyed layers would be entrapped between two surfaces and lead to a decreased amount of effective contact area and also scratch the surfaces. This phenomenon, which is called “galling,” is a form of adhesive wear in which metal rubs off one surface and sticks to the other.[30] This is probably the reason for the decreased value of the preload and removal torque in the last cycles. According to a study by Kim et al,[20] the brittle characteristic of titanium screws might be attributed to the body-centered cubic (BCC) crystal structure of them in comparison to face-centered cubic (FCC) in gold ones.

The results of the present study confirm the findings of Weiss et al,[13] Ricciardi Coppedê et al,[31] and Lee et al,[32] who also demonstrated that repeated opening/closing cycles caused loss of torque retention. Though preload was not directly measured in the present study, the results are consistent with the findings of Ortorp et al,[33] which displayed some decay in preload with repeated tightening. Although Byrne et al[11] also reported that all screw types display some decay in preload with repeated tightening, the result was different depending on screw type. The gold alloy screw and the gold-coated screw showed deterioration in preloads, while preloads obtained by the titanium alloy screw were essentially stable. It is presumed that gold coating that acts as a solid lubricant is damaged during insertion and becomes less effective. Bernardes et al[34] also concluded that tightening/untightening sequences did not result in any significant loss of initial preload in titanium and diamond-like carbon–coated titanium screws. Nevertheless, Tzenakis et al[19] showed higher preload values after 5 or 10 repeated uses of salivary contaminated gold prosthetic retaining screws. They stated that this escalation in preload is attributed to the decrease in frictional forces. However, it is not clear how much friction is enough to maintain the preload. That is why comparing the results of the studies that directly measure the preload with the ones that report the removal torque is not always easy. Further studies are needed to determine when the friction is too reduced to prevent screw loosening. Considerable variation between the results of different studies may be attributed to the different materials, methodology, and statistical analysis they used. For instance, experiments have measured preload from rotational angle,[12] from compression in the implant assembly,[35,36] from screw elongation,[3] or by strain gauges.[19]

The results of the present study indicated that although there was a decrease in RTVs throughout the repetitions, the authors observed relatively high variations in the torque values even between the samples of the same group. Coefficient of friction is controlled by intrinsic metallurgic properties of the raw material and the manufacturing process, which determines the geometric design and quality of the surface finish.[2] That is why previous studies showed that not only screws from different manufacturers[37] but also screws from different lots made by the same manufacturer[37,38] could withstand different maximum preload torque before fracture. Manufacturers should have good control over material properties and the manufacturing process.

Since in a clinical situation, loading of the screw joint is an important contributor to decrease the preload, in the present study, this factor has been simulated by cyclic loading. As mentioned earlier, because the crowns were stable enough, exclusion of cement could not influence the cyclic loading outcomes. The results of the present study indicate that after cyclic loading that simulates 6 months of clinical services, the value of removal torque is extremely decreased. However, the number of I/R cycles or changing the used screw with a new one before loading could not significantly increase the value of removal torque.

Nevertheless, considering the greater mean and minimum torque loss values of the second group, it is possible the differences become significant in a long-term clinical simulation. Delben et al in 2011[39] and 2014[17] evaluated the effect of retightening and mechanical cycling on preload maintenance and reported that although a reduction in torque value was noted initially and after mechanical cycling, enough torque was maintained to resist screw loosening. This result may be explained by retightening the screws after each period of 100,000 cycles. Ricciardi Coppedê et al[31] and Cardoso et al[21] also reported a lower torque loss ratio in comparison to the present study. This is possibly due to retorquing the screws every 15 minutes during loading, in addition to the much lower amount of load they applied. Dhingra et al[40] and Butignon et al[41] also noted that while there was a loss of torque after loading, the stability of the implant-abutment joint was not affected. This might be due to the method of these studies in which the screws did not endure repeated closing/opening cycles.

Another notable finding in the present study was that using a new screw could not significantly increase the value of removal torque. It seems that restricting the amount of screw tightening is more important than replacing the screw with a new one when an abutment is definitively placed. There are a few studies[21,22] that have evaluated the effect of replacing a used screw with a new one. Similarly, Cardoso et al[21] found no evidence to prove this procedure alone could increase resistance to loosening, possibly due to a modification that had already occurred in the internal threads of the implant. However, Guzaitis et al[22] stated that to achieve maximum removal torque and maintain preload, after 10 screw insertion cycles, a new screw should be used when inserting the definitive restoration.

SEM surface analysis of the screw head showed that after successive tightening and loosening, there is a substantial distortion in the internal hexagonal slot of the screw head. Additionally, it is supposed that regarding a few difficulties in manipulating the screwdriver and less visual approach inside the mouth, wear or distortion of the screw slot would be more noticeable. This distortion could cause a rotational freedom between the driver tip and the slot of the screw head. The finding above is also compatible with the findings of Kim et al.[20] Due to differences in manufacturing, it would have been desirable to assess a larger number of screws with SEM and average the findings in future studies.

There were some limitations to this study inherent to the in vitro condition. As the complex biomechanics of an oral condition could not exactly be simulated, caution should be exercised in interpreting the results. Thus, it should be validated in a clinical condition.

CONCLUSIONS

Within the limitations of this in vitro study, it was concluded that using a new screw could not significantly increase the value of removal torque. It seems that restricting the amount of screw tightening is more important than replacing the screw with a new one when an abutment is definitively placed.

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