The Relationship Between Time of Retightening and Preload Loss of Abutment Screws for Two Different Implant Designs: An In Vitro Study

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The loosening of an abutment screw is one of the most frequent complications in implant-prosthetic rehabilitation, especially for single-crown cemented prostheses. This complication is due to several mechanical factors including type of connection, abutment-screw geometry, settling effects, and cyclical load. The purpose of the present in vitro study was to compare and associate different times of retightening with reductions in preload losses. We evaluated 40 internal hexagon dental implants and 40 external hexagon dental implants, with their related abutment screws. The implants were embedded in acrylic resin in cylindrical polyvinyl chloride tubes (26 mm diameter, 20 mm height). The abutments were fixed to the implants with screws to an initial torque of 35 Ncm using a digital torque meter with decimal precision. Two different types of connection were randomly divided in 4 subgroups of 10 samples each. One subgroup was used as control. The test groups underwent retightening to the same initial torque at increasing times from initial torque application for tightening of the abutment screws, to their retightening at 2 minutes, 5 minutes, and 10 minutes. The retightening time of 2 minutes shows significantly reduced preload loss. Randomized clinical trials are strongly required to provide clinicians with a beneficial standardized protocol of retightening that can be applied in routine clinical practice.

Key Words: dental implants, repeated tightening, settling effect, tightening torque, preload, abutment-screw loosening

INTRODUCTION

Research and clinical experience reported in the literature have shown high incidence of abutment-screw loosening. This is described as a frequent complication of implant-prosthetic rehabilitation that mainly occurs in the first year of loading. Recent studies have concluded that the factors that contribute to screw-joint instability include inconsistent tightening, misfit between implant and abutment or between abutment and prosthesis, poorly machined components, excessive occlusal forces or non-axial loading, settling of surface micro-roughness, and/or inadequate abutment-screw geometry and design.[1,2]

An abutment screw will loosen only if the forces involved in disengaging of the joint are greater than the clamping forces that keep the two parts together, which can occur through elongation of the abutment screw, placing of the shank and thread in tension, and elastic recovery.[3,4] To prevent an abutment screw from loosening, it is not necessary to eliminate the separating forces, but only to minimize them.[4] When the clinician applies torque to an abutment screw to tighten together its components, the tightening torque creates a preload within the abutment screw. The preload represents the initial load on the abutment-screw joint, which can be compared to a frictional tension generated by the tightening between the abutment-screw thread and the internal thread of the implant, and between the head of the screw and the abutment. This is responsible for the clamping forces that are created. The preload achieved is proportional to the torque applied; thus, an increase in preload can maximize the stability of the abutment-screw joint.[4–6] Experienced clinicians recommend that a screw is tightened to the maximum preload possible, which means a torque that is approximately 75% of the torque needed to cause plastic deformation of the mating surfaces, thereby causing abutment-screw failure.[4]

In an attempt to better define the problem of abutment-screw loosening, much effort has been directed toward achieving a more predictable method for tightening abutment screws to prevent the "settling effect" (ie, embedding relaxation).[7] Settling effect is the main cause for abutment-screw loosening, as well as how the mating surfaces change when the abutment screw is tightened. Settling effect is an important variable that influences screw stability.[8] The mechanism of the settling effects depends on the surface irregularities, as viewed microscopically. These micro-roughness

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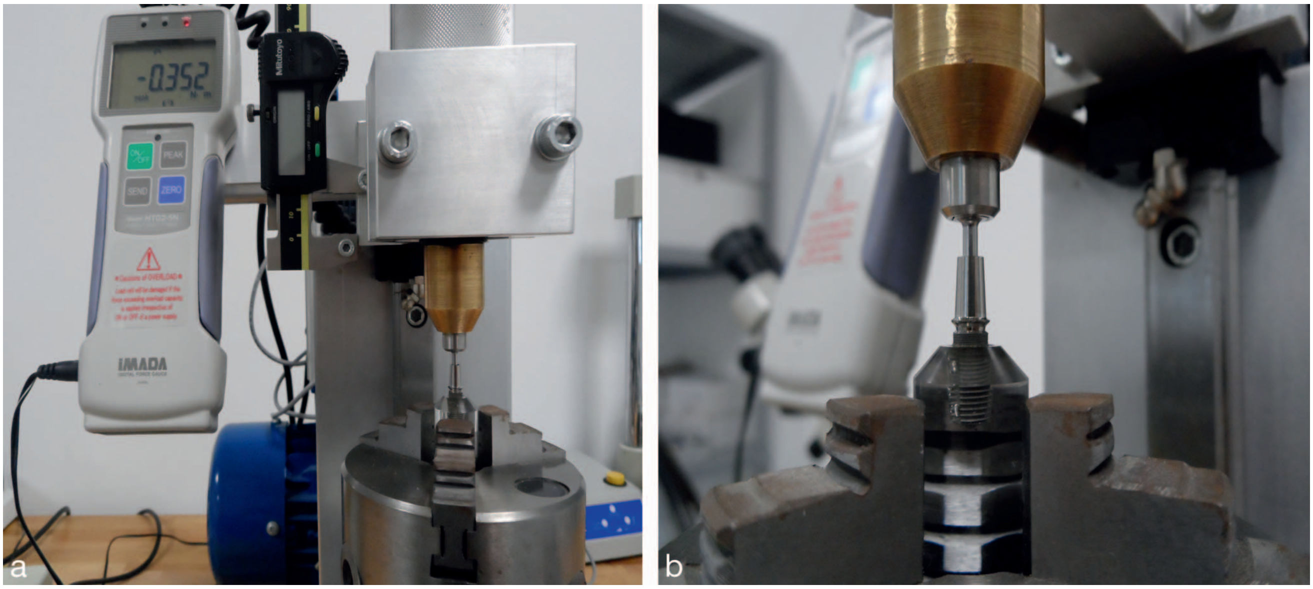


FIGURE 1. Photograph of the set-up of the experimental model used in the present study. (a) Implant positioned in the torque application device for tightening torque to be applied to the screw (*right*). The readings of the digital torque meter (*left*) were then recorded as the initial tightening torques, and as the retightening torques at the defined times. (b) Close-up side view of the positioning of the implant for torque application to the screw.

spots are inevitably present, although the internal thread of the implant and the screw thread are machined to be perfectly smooth. High spots represent the only contact points when the initial tightening torque is applied, and they prevent the maximum contact of the two components. Under load, the micro-roughness of all the metal mating surfaces can flatten slightly.[4–6] This occurs initially in the first few seconds or minutes after tightening the abutment screw and, as a result, it is possible to note a loss in the preload. Consequently, the clamping forces are also reduced, and the detorque values are always lower than the initial tightening torque.[9,10] It has been reported that 2% to 15% of the initial preload is lost because of settling effects.[5,11]

The amount of settling depends on the initial condition of the rough spots on the surface, on their hardness, and on the magnitude of the load applied. The greater the roughness of the surface and the loading forces, the greater the settling effect. An easy method to prevent screw loosening is to ascertain that the abutment screw is tightened with an adequate initial torque. Then it has been hypothesized that the implant/abutment joint will need to be retightened after the initial placement, that is, when the screw is inserted.[9,10] However, few data exist on the effects of repeated tightening of abutment screws.

An in vitro protocol to reduce these settling effects was suggested by Dixon et al[5] and followed and supported, again in vitro, by Bakaeen et al[10] and Siamons et al[9] Their studies showed that it is possible to regain preload by applying a retightening torque again 10 minutes after the first tightening, suggesting that this technique should be used as a routine clinical procedure. In contrast with these conclusions, Tzenakis et al[12] reported that in an in vitro model system, about half of the preload is lost immediately after torqueing, whereas the rest is lost gradually over a 5-minute period. For this reason, they suggested retightening of the abutment screws 5 minutes after the first tightening torque. In their opinion, a longer time interval between the torqueing and retightening might allow further reductions in the preload.

However, to the best of our knowledge, there have not been any further studies, either clinical or in vitro, that have been designed to clarify the timing of the retightening to obtain the minimal loss of the preload. The aim of this in vitro study was therefore to investigate the influence of the time to retightening the abutment screw on the preload loss with two different implant designs: internal and external hexagon designs on the implants. The factor investigated was thus the most effective time for retightening over the first 10 minutes following initial tightening, in terms of obtaining minimal loss of preload.

MATERIALS AND METHODS

Samples and materials

Forty internal hexagon dental implants (3.8 × 15 mm) and 40 external hexagon dental implants (3.8 × 15 mm; WAY Milan, Geass S.r.l., Udine, Italy) were selected, along with their respective abutments and titanium screws (WAPM0014184, Geass S.r.l.). These were defined as the two experimental groups: the internal group (IG) and the external group (EG), respectively.

Instrumentation and measurements

The implants were embedded in acrylic resin (Orthojet, Lang, Ravelli, Italy) in cylindrical polyvinyl chloride tubes 26 mm in diameter and 20 mm in height, taking care to position the implants in the centers of the tubes (Figure 1). The tubes were

Table

Mean parameters recorded for the experimental groups†

Group	Torque Force (Ncm) Initial	Retightening	Detorque	Loss	% Loss	Student's *t* Test
IG0	35.1 ± 0.1	–	31.2 ± 1.6	3.9 ± 1.6	11.1	
IG2	35.2 ± 0.4	35.7 ± 0.9	33.6 ± 1.6	2.1 ± 1.5	5.8	*
IG5	35.0 ± 0.1	35.2 ± 0.1	30.6 ± 3.1	3.2 ± 1.2	9.1	
IG10	35.0 ± 0.2	35.3 ± 0.2	31.7 ± 1.1	3.6 ± 1.1	10.2	
EG0	35.2 ± 0.2	–	30.9 ± 3.2	4.2 ± 3.2	12.0	
EG2	35.1 ± 0.2	35.7 ± 0.9	33.3 ± 1.3	2.0 ± 1.3	5.7	*
EG5	35.0 ± 0.2	35.5 ± 1.0	32.5 ± 1.9	2.9 ± 1.7	8.3	
EG10	35.1 ± 0.3	35.2 ± 0.2	31.6 ± 1.1	3.7 ± 1.0	10.5	

*$P < .05$ vs. control.

†Data are means ± standard deviation (n = 9, 10 for each subgroup). IG indicates internal hexagon group; EG, external hexagon group; retightening was carried out 2, 5 and 10 min after initial torque force had been applied.

placed at the base of a torque application device (Morsa, Geass S.r.l.), which kept them from rotating when the tightening torque was applied to the abutment screw (Figure 1). A digital torque meter (HTG2-5 N digital torque gauge; Imada, Toyohashi, Japan) was placed at the top of the device, and the torque readings were expressed as Ncm, taken to one decimal place (Figure 1). To control for experimenter bias, the data were collected by the same operator at the same time in the morning hours, over 3 consecutive days.

Procedures

The abutments were fixed to the implants with screws, with the application of a torque of 35 Ncm, according to the manufacturer recommendations. The placement torques were measured using the digital torque meter. A square hand wrench (UNCC0014242; Geass S.r.l.) was attached to the torque meter to allow adequate connection between the torque meter and the abutment screws. Both the IG and the EG groups were randomly divided in four subgroups that were formed by 10 samples each. IG0 and EG0 were the respective control groups, where no retightening was applied. The test groups of IG2, IG5, IG10, and EG2, EG5, and EG10, each underwent retightening to the same initial torque at increasing times from the initial tightening of the abutment screws to their retightening, of 2 minutes, 5 minutes, and 10 minutes, respectively. Finally, at 30 minutes from the initial tightening of the abutment screws, all of the dental implants were detorqued, using the digital torque meter to determine and record the removal torques.

Statistical analysis

IBM SPSS Statistic v 20.0 (SPSS Inc, Chicago, Ill) was used for the data analysis. The datasets (n = 10, per condition) were initially examined according to Chauvenet's Criterion,[13] which defined five (of a total of 80 data points) as outliers, all of which belonged to different experimental subgroups. These same five data points were also defined as outliers in a supporting analysis according to Pierce's Criterion.[14] Following the removal of the outliers, the data were analyzed for significance between the differences in the initial torque loads (IG0; EG0) and the retightening torque loads (IG2, 5, 10; EG2, 5, 10) and the 30-minute detorque loads. The data are thus expressed as the torque load losses within each experimental group (IG; EG) and are presented as means ± standard deviation (SD). Student *t* tests were used to determine the significances of the preload loss compared to the control groups. After verification of the normal distribution of the data according to Shapiro-Wilks tests, 1-way analysis of variance (ANOVA) was used to determine which of the different times of retightening were statistically significant. A P value of $<.05$ was considered statistically significant. The methodology was reviewed by an independent statistician.

Results

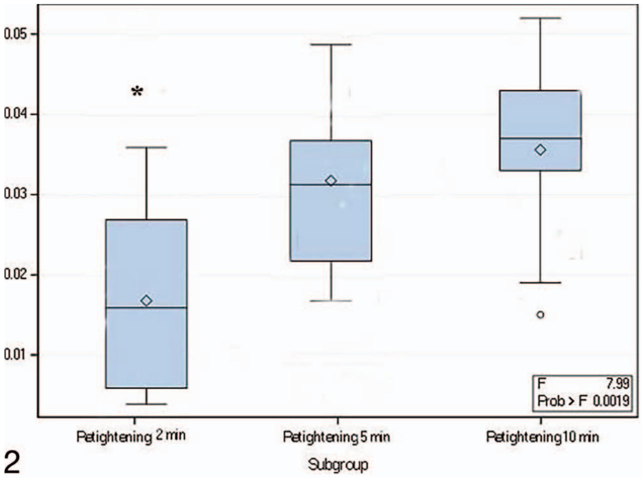
The forces recorded for the initial torques showed no significant differences across all the subgroups, with the overall mean torques given in Table 1. The initial torque forces ranged from 35.0 Ncm to 35.2 Ncm, and the retightening torque forces ranged from 35.2 Ncm to 35.7 Ncm, again with no significant differences among the retightening subgroups or from the initial torque forces. The final detorque forces ranged from the minimum of 30.6 Ncm for the IG group with 5-minute retightening (IG5), to the maximum of 33.6 Ncm for the IG group with 2-minute retightening (IG2). As shown in Table 1, for both the IG and EG groups, there were significant benefits over the control condition for retightening after 2 minutes ($P < .05$).

One-way ANOVA demonstrated statistical significance for the preload losses for the IG2 and EG2 subgroups compared to the IG10 and EG10 subgroups, respectively (Figures 2 and 3). The torque losses did not significantly differ between the EG subgroups compared to the respective IG subgroups (Figure 4).

Discussion

Torque losses (incidence, 2%–15%) and the potential consequent abutment disconnection represent the most frequent mechanical complication in prosthetic rehabilitation of such implants.[8] The settling effect is one of the factors that contributes to detorqueing of the connection screw, due to the load distributed on all of the metal interfaces.[9]

In the case of these prosthesis implants, the settling effects occur between the inner part of the fixture and the abutment



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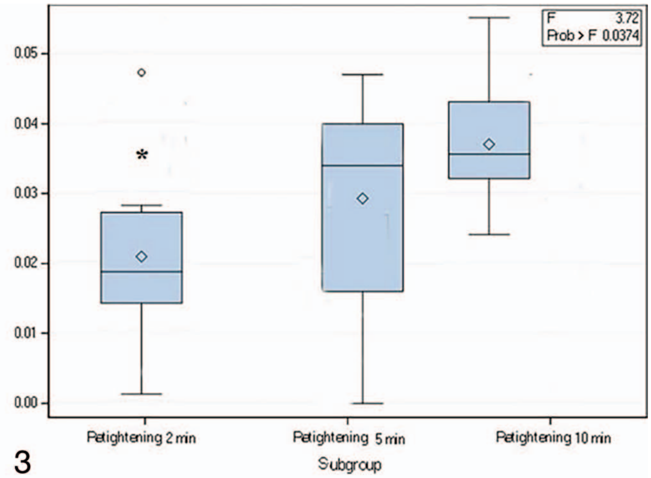

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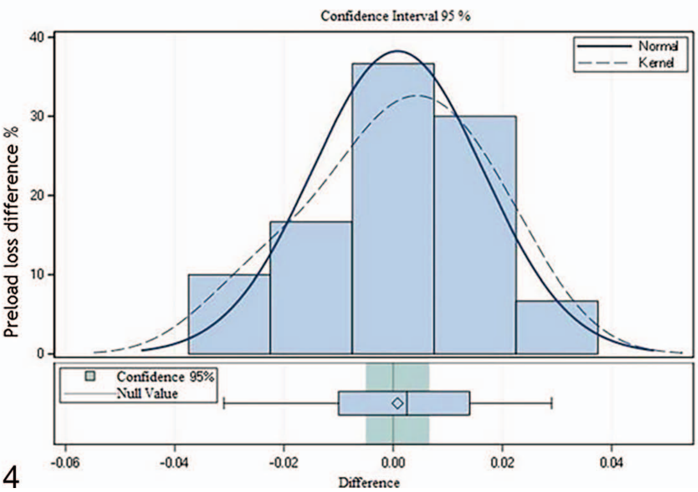

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Figures 2–4. Figure 2. Box plot showing the data distribution of the preload loss for the IG2, IG5, IG10 groups and the significance ($P < .05$) from the 1-way ANOVA analysis. *Values from the 2-minute retightening were significantly different to the other two groups. **Figure 3.** Box plot showing the data distribution of the preload loss for the EG2, EG5, EG10 groups and the significance ($P < .05$) from the 1-way ANOVA analysis. *Values from the 2-minute retightening were significantly different from the other two groups. **Figure 4.** Diagram depicting the Student *t* tests comparing the preload losses of the EG group vs the IG group. The differences between the two groups were not significant.

screws, between the superior part of the fixture and the inferior part of the abutment, and between the superior part of the abutment screws and the abutment surface. The extent of the settling effect depends on the contact surfaces, the hardness of the material, and the load.[9] Indeed, settling effects occur because some areas remain rough after the manufacture of the component parts. Therefore, the initial tightening serves to smooth the contact surfaces.

When the forces generated by the settling effect are greater than the elastic limit of the screw, screw loosening will take place. The main consequence of the settling effect is the loss of 2% to 15% of the initial preload. The preload is defined as the compression force that occurs between the abutment and the fixture as a consequence of the tightening torque.[4–6] A method to quantify the initial preload loss is the measurement of the initial removal torque of an abutment screw. Earlier studies indicated that the initial removal torque is lower than the initial tightening torque. In particular, this was confirmed in the Siamos study,[9] where they compared the tightening and removal torques, and where the removal torques were indeed lower than the initial tightening torques.

The data reported in the present study show decreases in the preload for both of the experimental groups (ie, the internal group, IG, and the external group, EG), with the removal torques lower than the initial tightening torques. Specifically, the preload decrease with no retightening was 11.6% across both control subgroups (IG0, EG0).

To avoid such losses, Dixon et al[5] suggested retightening the joint screws after 10 minutes, which can slow the preload reduction. Their protocol was supported by studies of Bakaeen et al[10] and Siamos et al,[9] which indeed indicated that retorqueing after 10 minutes can reduce the settling effect. This procedure was thus proposed as standard for routine clinical practice. However, the data reported in the present study do not support this timing, as the retightening procedure after 10 minutes did not provide any advantages in terms of preload decrease.

Tzenakis et al[12] also studied the role of the coefficient of friction in the settling effect in vitro and reported that half of the preload decrease occurred immediately after the initial tightening torque. Therefore, they suggested to retighten the abutment screws after 5 minutes, which was indeed adapted more recently by Siadat et al[15] in their investigation of potential implant connection type effects on microleakage and screw loosening. The data from the present study support this protocol, to confirm the advantages in terms of decreased settling effect losses by applying the retorqueing after 5 minutes, or less.

Similarly, in a computer model using finite elements methods, Bulaqi et al[16,17] reported that the loss of preload occurs earlier, where the preload losses in the first 2 seconds after the first initial torque are linear, again indicating that earlier retorqueing can better replace the losses of the initially applied torque. This assumption is again confirmed by the data in the present study, where for both groups, the early retightening performed 2 minutes after the initial torque showed significant improvements against reduction of the preload torque.

Of note, and also including the present study, the data regarding the levels and rates of preload loss and the potential to minimize these through retightening of the abutment screws have to date been performed in vitro. Although at least one of these studies introduced a "physiological" aspect in terms of lubrication with human saliva,[12] the direct adoption of such data to the clinical situation has to remain an open question. Therefore, the main limitations of these studies relate to lack of the true structure of the gums and alveolar bone, and also immunological responses that would occur following the in vivo situation. Furthermore, the design of the present study did not include any analysis of the potential confounding factor of abutment screw roughness prior to application. However, in the absence of data from randomized clinical trials, these in vitro studies now indicate that early retorqueing (2 to 5 minutes following initial tightening) is more effective than later retorquing (10 minutes or more) to minimize preload losses.

Conclusions

Within the limitations of the present study, we can conclude that: (1) both of the experimental groups (ie, the internal and external groups) had detorque values that were lower than the initial tightening torque, as a consequence of the settling effect; (2) the highest preload losses were recorded in both groups with retightening of the abutment screws after 10 min; and (3) the lowest preload losses were recorded in both groups with retightening of the joint screws after only 2 minutes.

In conclusion, these data indicate retightening of the abutment screws after 2 minutes with the same initial torque to reduce the settling effect, with the potential for reduced loosening, and consequent failure of the abutment screws that can arise from such preload torque losses. These data need to be further supported by randomized clinical trials to provide clinicians with a standardized protocol to apply in routine clinical practice.

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Note

The authors state that they have no conflicts of interest.

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