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Dynamic fatigue performance of implant-abutment assemblies with different tightening torque values[1]

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Abstract. Implant-abutment assemblies are usually subject to long-term cyclic loading. To evaluate the dynamic fatigue performance of implant-abutment assemblies with different tightening torque values, thirty implant-abutment assemblies (Zimmer Dental, Carlsbad, CA, USA) were randomly assigned to three tightening groups (24 Ncm; 30 Ncm; 36 Ncm), each consisted of 10 implants. Five specimens from each group were unscrewed, and their reverse torque values recorded. The remaining specimens were subjected to a load between 30N～300N at a loading frequency of 15 Hz for 5×10^6 cycles. After fatigue tests, residual reverse torque values were recorded if available. In the 24 Ncm tightening group, all the implants fractured at the first outer thread of the implant after fatigue loading, with fatigue crack propagation at the fractured surface showed by SEM observation. For the 30 Ncm and 36 Ncm tightening groups, a statistical significant difference ($p<0.05$) between the unloaded and loaded groups was revealed. Compared with the unloaded specimens, the specimens went through fatigue loading had decreased reverse torque values. It was demonstrated that insufficient torque will lead to poor fatigue performance of dental implant-abutment assemblies and abutment screws should be tightened to the torque recommended by the manufacturer. It was also concluded that fatigue loading would lead to preload loss.

Keywords: Dental implants, fatigue testing, reverse torque value, preload

1. Introduction

Since Branemark introduced the osseointegration concept, dental implants have been successively used for edentulous patients [1,2]. However, long-term clinical follow-ups reported biological or mechanical complications after osseintergration has been achieved. Such mechanical complications include screw loosening, implant system deformation, and fracture. Abutment screw loosening is one of the most frequent complications in single-tooth implant restoration. According to a systematic review conducted by Pjetursson, B.E. et al. [3], abutment screw loosening is found in 5.3% of implants in one

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year follow-up. Systematic reviews of the literature revealed the incidence of screw loosening to be 5.8% -12.7% after five years [4,5].

Screw loosening may cause implant or screw fracture, inadequate occlusal force distribution and possible osseointegration failure. In addition, screw loosening would also lead to micromotion at the implant-abutment interface while chewing. Micromotion has been regarded as one of the main causes of microgaps between implant and abutment [6]. Such microgaps could act as reservoirs for bacteria, and may cause inflammatory reaction in peri-implant soft tissues [7]. Some of those problems are catastrophic to the implant. They may cause an increase in subsequent visits for maintenance, which is time consuming and inconvenient to both the patient and the doctor. The stability of implant-abutment assemblies and their resistance against occlusal force are crucial to long-term clinical success.

Many factors can contribute to screw loosening, such as inadequate tightening torque, mechanical overload, screw setting, and mismatch in screw material and design [8]. These factors may affect the preload between implant and abutment. Preload is defined as the clamping force between abutment and implant and is derived from the tightening torque applied to the retaining screw [9]. The elastic recovery of the screw creates the clamping force that keeps the screw thread tightly secured to the implant internal threads, and holds together the screw head and its seat [10]. The screw tightening torque value plays an important role in the preload of a system. However, the effect of tightening torque values on the fatigue performance of implant-abutment assemblies has rarely been studied.

In this study, the dynamic fatigue performance of implant-abutment assemblies with different tightening torque values was investigated. The primary objective of this study was to evaluate the effect of different tightening torque values on the fatigue performance of implant-abutment assemblies. Meanwhile, the other objective was to investigate the effect of fatigue loading on abutment screw reverse torque values.

2. Experimental procedures

2.1. Materials and methods

Thirty implant-abutment assemblies (Zimmer Dental, Carlsbad, CA, USA) were randomly assigned to three tightening groups (less than recommended torque, 24 Ncm; recommended torque, 30 Ncm; more than recommended torque, 36 Ncm), each consisted of ten implants. The implants were tapered, 13 mm in length and 3.7 mm at the neck, with 20^{o}-angle abutments. Five implant-abutment assemblies from each group were randomly selected to constitute the control group; they were unscrewed, and their reverse torque values recorded. A digital torque meter (HN-5, Haibao, China) was used to measure the tightening torque and reverse torque. The remaining specimens were subjected to fatigue tests according to ISO14801:2007 guidelines [11].

A fatigue testing machine (E1000, Instron Ltd, USA) with 1000 N-load capacity, driven under load control, was used to perform the fatigue tests in this study. The steel jig was individually fabricated with an angle adjustable stand. Individually fabricated steel balls (6 mm in diameter) were glued to the abutment with two-component methyl methacyllate adhesive (X60, HBM, Germany). The steel jig fixed the specimen rigidly at a distance of 3.0 mm±0.1 mm apically from the nominal bone level to simulate marginal bone loss. The distance between the center of the hemisphere to the fixing plane was 11 mm±0.1 mm. The overall setup for the fatigue tests is depicted in Figure 1.

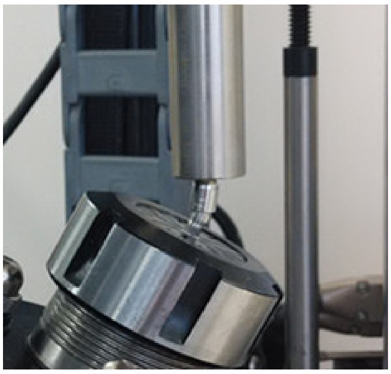

Fig. 1. Fatigue testing device.

A compressive cyclic sine wave load between 30 N and 300 N at a loading frequency of 15 Hz was applied to the remaining specimens for 5×10^6 cycles, or until failure. After the fatigue tests, the residual reverse torque values were recorded if available.

2.2. Testing environments

The tests were conducted by the same operator. All tests were performed in vitro in a dry area and at room temperature (24°C±1°C), with humidity of 53%±1%.

2.3. Statistical method and fractured surface observation

Statistical analysis was conducted using SPSS software (version16, SAS Institute Inc, Cary, NC) with a 0.05 level of statistical significance assumed prior to tests. Descriptive statistics of reverse torque values and residual reverse torque values values were calculated, and comparisons were performed with Student's t-test for RT and reverse torque values and residual reverse torque values. A scanning electron microscope (EVO L18, Carl Zeiss Ltd, Germany) was used to observe the fractured surfaces of specimens. Prior to insertion to the Scanning electron microscope (SEM), the fractured surfaces were coated with a thin layer of gold.

3. Results

3.1. Scanning electron microscope (SEM) observation of fractured specimens

In the 24 Ncm tightening group, all the implant and abutment screws fractured at the root of the first outer thread of the implant. SEM micrographs of the fractured implants were obtained. Figure 2 shows a fractured surface, and Figure 3 shows the fatigue striations and final stage overload zone of the implant.

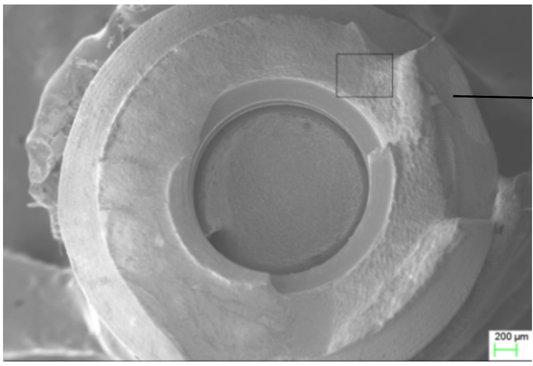

Fig. 2. SEM micrograph of a fractured surface.

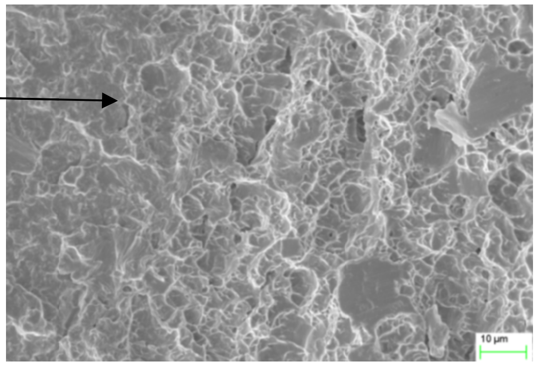

Fig. 3. SEM micrograph showing the fatigue striations and final stage overload zone of the implant.

Table 1

Average values of RT and RRT, and P-values between RT and RRT

Tightening torque value(Ncm)	RT (Ncm) (SD)	RRT(Ncm) (SD)	P
24	21.74 (0.26)	-	-
30	27.48 (0.28)	21.08 (1.12)	＜0.05
36	31.88 (0.37)	27.74 (0.94)	＜0.05

3.2. Average reverse torque values of the control group (RT) and average residual reverse torque values (RRT)

In the 30 Ncm and 36 Ncm tightening groups, the implant-abutment assemblies tested under fatigue loading exhibited torque losses. According to the t-test, statistically significant differences ($p<0.05$) were found between the control and test specimens of each group. Table 1 shows the average reverse torque values of the control group (RT) and average residual reverse torque values (RRT).

3.3. The amount of torque losses

In order to perform comparison between different groups, the mean percentage of tightening torque was calculated. The ratio of the control group (RT) to the tightening torque value can indicate the amount of torque loss before loading, whereas the ratio of average residual reverse torque values (RRT) to tightening torque indicates the amount of torque loss after loading.

The 24 Ncm tightening group exhibited a 9.42% torque loss. The 30 Ncm tightening group showed an 8.40% torque loss without loading and a 29.73% torque loss after loading. The 36 Ncm tightening group exhibited a 11.44% torque loss without loading while a 22.94 % torque loss after loading

4. Discussion

After fatigue loading, the specimens in the 24 Ncm tightening group fractured at the root of the first outer thread, which is near the clamping plane, and showed the greatest stress concentration [12]. SEM revealed fatigue crack propagation at the fractured surface. Meanwhile, screw loosening or fracture was not observed in the 30 Ncm and 36 Ncm groups after fatigue loading. This finding coincides with those of other researchers [13,14] who observed that lower tightened implant-abutment assemblies failed to survive fatigue tests, while implants assemblies in the recommended and over-tightened torque groups had intact implant-abutment interfaces. Some other researchers [15,16] discovered a linear relationship between tightening torque and screw preload. As the torque increases, the preload gets greater (up to the ultimate strength), resulting in greater force it requires to loosen the screw. Lee, F.K. [15] reported that screws over-tightened by 20% exhibited higher implant critical bending moment and the least amount of micromotion with no apparent compromise of the implant system.

The purpose of tightening a screw is to obtain optimum preload, which will maximize the fatigue life and protect the screw from loosening [17]. If the joint is compressed, preload will be lost; the screw and the interface have to withstand plastic deformation and the joint may separate [18]. Bickford [9] described screw loosening as a two-stage process. Firstly, external functional forces applied to the screw joint gradually decrease the tightening force. Vibration and micromotion lead to the backing off of the screw, reducing the effective preload and diminishing the screw's ability to maintain stability of the joint. Secondly, preload decreases and exceeds a critical level, allowing threads to turn, and thus losing the intended screw joint function. If the screw loosens and the preload falls below a critical level, stability of the joint may be compromised and failure of the joint may be caused [19]. In this study, the fracture of the implant-abutment assemblies in the 24Ncm tightening group may be caused by insufficient preload resulting from the reduced tightening torque.

As suggested by the available literature, offering the optimum torque is critical for clinical use. The optimization of the torque should be based on the occlusal forces applied to the implant-abutment assemblies, so that the osseointegrated bone-implant interface will not be damaged [20]. If the screw tightening torque is lower than the appropriate tightening torque required, screw loosening may occur. Moreover, screw loosening is followed by a considerable risk of implant fracture [21]. Using higher torque values would provide the implants with increased resistance to joint separation and greater screw stability. However, overly high torque values may exceed the yield strength of the screws. Plastic deformation would lead to the loss of mechanical properties of the screws [22]. Meanwhile, the osseointegration of bone-implant interface may be affected. Therefore, it is crucial to apply the correct amount of tightening force. When tightening the screws, manufacturer's recommendations should be followed, and torque wrenches should be calibrated to ensure appropriate tightening torque [23].

In this study, we used reverse torque value to evaluate preload. Reverse torque value has been used as a measurement of preload in numerous studies to evaluate interface stability following fatigue tests [24–27]. In this study, the mean reverse torque values of the control group were lower than the mean tightening torque values. This finding is in agreement with that Saboury, A. et al. [28], who reported that reverse torque values are less than the initial tightening torque values, the former ranging from 80.9% to 93.1% of the latter. The torque loss may be explained by the fact that the screws are subjected to a mechanical effect known as embedment relaxation [29,30]. As the contacting surface between the screw and the implant cannot be machined perfectly smooth, high spots will be the only contacting surfaces when the initial tightening torque is applied. The contacting surface will make some adaption to smooth the surface, thus leading to preload loss.

After fatigue tests, the mean residual reverse torque values of the tested specimens were lower than that of the control group. This result is consistent with those of other studies. Vianna, C.A. et al. [31] reported torque loss in relation to the tightening torque loss of 36.25% without fatigue loading and 40.85% after fatigue testing. Ricciardi, C.A. et al. [32] measured torque loss of 32% for the control group and 37.2% for the loading group. When fatigue loading is applied to an implant assembly, further torque loss occurs due to the accommodation of the surface inside the implant [31]. After the abutment screw was removed from the implant, the abutment remained secured inside the implant due to friction generated by the contacting surface between the abutment and implant inner part. In the internal taper system, the screw plays a relatively minor role in retaining the implant-abutment interface. The aforementioned friction between the abutment and the implant keeps the two parts together [33].

5. Conclusion

In this study, the dynamic fatigue performance of implant-abutment assemblies with different tightening torque values was investigated. It was demonstrated that the variation of tightening torque value has significant influence on the fatigue performance of implant-abutment assemblies. Insufficient torque will lead to poor fatigue performance of implant-abutment assemblies, and the abutment screws should be tightened to the torque recommended by the manufacturer in order to prevent mechanical complications.

Compared with those of the unloaded specimens, reverse torque values of specimens after fatigue loading declined. It was also concluded that fatigue loading would lead to preload loss.

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