Effects of Abutment Screw Coating on Implant Preload

Jae-Kyoung Park, DDS, MSD, PhD,[1] Jin-Uk Choi, DDS, MSD,[2] Young-Chan Jeon, DDS, MSD, PhD,[3]
Kyung-Soo Choi, DDS, MS,[4,5] & Chang-Mo Jeong, DDS, MSD, PhD[3]

[1] Clinical Instructor, Department of Prosthodontics, School of Dentistry, Pusan National University, Busan, South Korea
[2] Post-Graduate Student, Department of Prosthodontics, School of Dentistry, Pusan National University, Busan, South Korea
[3] Professor, Department of Prosthodontics, School of Dentistry, Pusan National University, Busan, South Korea
[4] Private Practice, Busan, South Korea
[5] Adjunct Instructor, Department of Prosthodontics, School of Dentistry, Pusan National University, Busan, South Korea

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Correspondence:
Chang-Mo Jeong, Department of Prosthodontics, School of Dentistry, Pusan National University, 10 Ami-dong 1 ga, Busan, 602, South Korea. E-mail: cmjeong@pusan.ac.kr

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Abstract

Purpose: The aim of the present study was to investigate the effects of tungsten carbide carbon (WC/CTa) screw surface coating on abutment screw preload in three implant connection systems in comparison to noncoated titanium alloy (Ta) screws.
Materials and Methods: Preload of WC/CTa abutment screws was compared to noncoated Ta screws in three implant connection systems. The differences in preloads were measured in tightening rotational angle, compression force, initial screw removal torque, and postload screw removal torque after 1 million cyclic loads. Preload loss percent was calculated to determine the efficacy of maintaining the preload of two abutment screw types in relation to implant connection systems.
Results: WC/CTa screws provided 10° higher tightening rotational angle than Ta screws in all three connection systems. This difference was statistically significant ($p < 0.05$). External-hex butt joint implant connections had a higher compression force than the two internal conical implant connections. WC/CTa screws provided a statistically significantly higher compression force than Ta screws in all three implant connections ($p < 0.05$). Ta screws required statistically higher removal torque than WC/CTa screws in all three implant connections ($p < 0.05$); however, Ta screws needed statistically lower postload removal torque than WC/CTa screws in all three implant connections ($p < 0.05$). Ta screws had a statistically higher preload loss percent than WC/CTa screws in all three implant connections ($p < 0.05$), indicating that WC/CTa screws were superior in maintaining the preload than Ta screws.
Conclusions: Within the limits of present study, the following conclusions were made: (1) WC/CTa screws provided higher preload than noncoated Ta screws in all three implant connection systems. (2) The initial removal torque for Ta screws required higher force than WC/CTa screws, whereas postload removal torque for Ta screws was lower than WC/CTa screws. Calculated Ta screw preload loss percent was higher than for WC/CTa screws, suggesting that WC/CTa screws were more effective in maintaining the preload than Ta screws. (3) Internal conical connections were more effective in maintaining the screw preload in cyclic loads than external-hex butt joint connections.

Endosseous dental implants have been highly successful in treating completely[1,2] and partially edentulous patients;[3,4] however, long-term clinical reports of dental implants have shown some biological and biomechanical complications.[5–7] Screw loosening is one of the more common prosthetic complications, particularly in single-tooth replacement therapy for dental implants.[8–10] Guidelines have been suggested to reduce such biomechanical complications.[11]

The clamping force from a screw provides a stable joint between the abutment and the implant fixture.[12,13] This clamping force, also known as preload, is generated by rotational torque force that elongates the screw within the material yield strength.[14] Higher preload of a screw provides a more stable joint, thus, less screw loosening is theoretically possible; however, actual preload is dependent on the finish of the interfaces, friction between the components, geometry, and material properties.[15] Since only 10% of the initial rotational torque force is transferred to preload and 90% is used to overcome the friction of the mating surface of the components,[16] manufacturers claim that higher preload is achieved with coated new screws.[17-18] Martin et al demonstrated that greater preload was produced with higher tightening torque, or by using an abutment screw that had reduced frictional coefficient treatment.[19] Exceeding manufacturers' recommended 30 Ncm of tightening torque can provide higher preload for a more stable implant-abutment connection joint; however, this method may introduce too much rotational and shearing force to the implant systems, particularly when they are placed in soft-quality bone, and the osseointegration process is not fully matured. Using the reduced frictional coefficient method may be a safer approach to provide greater preload for higher implant joint stability in compromised osseointegration situations.

Two types of connection system are widely used in dental implants, namely external-hex butt joint and internal conical interface. These two implant-abutment connections employ different mechanical principles to control the external force for joint stability and stress distributions.[20] An external-hex butt joint only stabilizes the connection between the abutment and the implant fixture by the axial preload of the abutment screw.[21] Occlusal force to the connection is concentrated at the abutment screw, thus the optimum preload is critical for joint stability and screw loosening.[22] Many internal conical connections have a Morse Tapered interface between the abutment and the fixture, creating frictional interference. This conical frictional fit creates wedging effects to improve the implant-abutment joint stability against the lateral force and helps to transfer the loading force along the conical surface to distribute the stress on the implant, ultimately reducing biological and biomechanical complications.[23-26] It may be possible that internal conical connections help the abutment screw retain greater preload after repeated loads since the loading stress is concentrated not only on the screw as in the external-hex butt joint implant systems.

The purpose of this experiment was to test the effects of a tungsten carbide carbon coating surface on the abutment screw preload in different implant connection systems.

Materials and methods

The present experiment used two different abutment screws and three implant-abutment connections from Osstem Implant (Seoul, South Korea). Both types of abutment screws were made of titanium alloys, but only one had tungsten carbide carbon (WC/CTa) coating surface; the other did not (Ta) (Fig 1). The three implant systems were US II, SS II, and GS II (Fig 2). The US II implant had an external-hex butt joint connection. The SS II implant had an internal conical connection with 8° Morse Taper with 2.8 mm collar neck for one-stage purpose. The GS II implant had an internal conical connection with an 11° Morse Taper.

Tightening rotational angle

Each of the three implant connection types was fixated with specially made metal jigs, and five WC/CTa screws and five noncoated Ta screws were tightened to 5 Ncm with correspond-

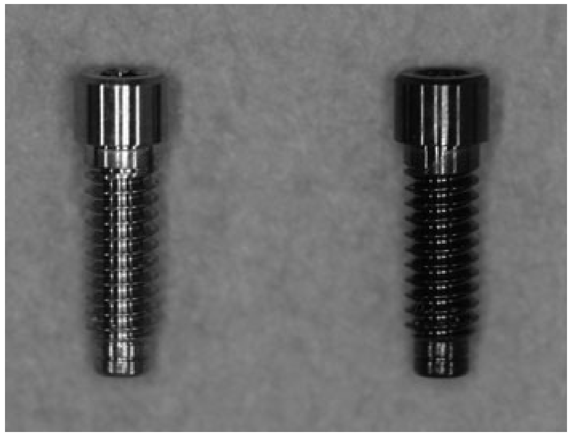

Figure 1 Two types of abutment screws: noncoated titanium alloy (Ta) screw (l), tungsten carbide carbon coating surface titanium alloy (WC/CTa) screw (r).

ing abutments using a digital torque meter (MGT12E, Mark-10 Corp, Hicksville, NY). A rotational angle measuring digital gauge (CT6Y-1, Autonics, Gyeonggi-do, South Korea) was set to zero. Then the digital torque meter continued to tighten the screw to 30 Ncm, and the rotational angle was measured. Each screw type had this measurement repeated five times.

Compression force

The clamping force generated by the rotational torque force to the abutment screw was directly measured using SlimLine Force Sensor (9132B21, Kistler, Switzerland). Because this sensor was not possible to place between the actual implant fixture and the abutment, models were made using the same material and connection configuration to the each implant system (Fig 3). The sensor was placed between the abutment and fixture model components, and a digital indicator (MI-15W, Senstech, Gumjung-gu Pusan, South Korea) was connected to measure the compression force generated by the rotational torque applied by the digital torque meter to each of the WC/CTa and Ta screws to 30 Ncm. Each implant connection system had five WC/CTa and Ta screws measured five times.

Screw removal torque before cyclic load

Each of the three implant connection types was fixated with the same metal jigs, and five (each) WC/CTa and noncoated Ta screws were tightened with corresponding abutment to 30 Ncm using a digital torque meter (MGT12E). Ten minutes later, 30 Ncm torque was reapplied with the same torque meter to compensate for the initial settling effect of the screw. The same digital torque meter was used to measure the screw-removal torque of each connection system with WC/CTa and Ta screws. A total of 30 implant-abutments with screw assemblies were used for the initial screw-removal torque measurements.

Screw-removal torque after cyclic load

As described previously for the before-cycling load, each implant system was fixated and connected with two screws of

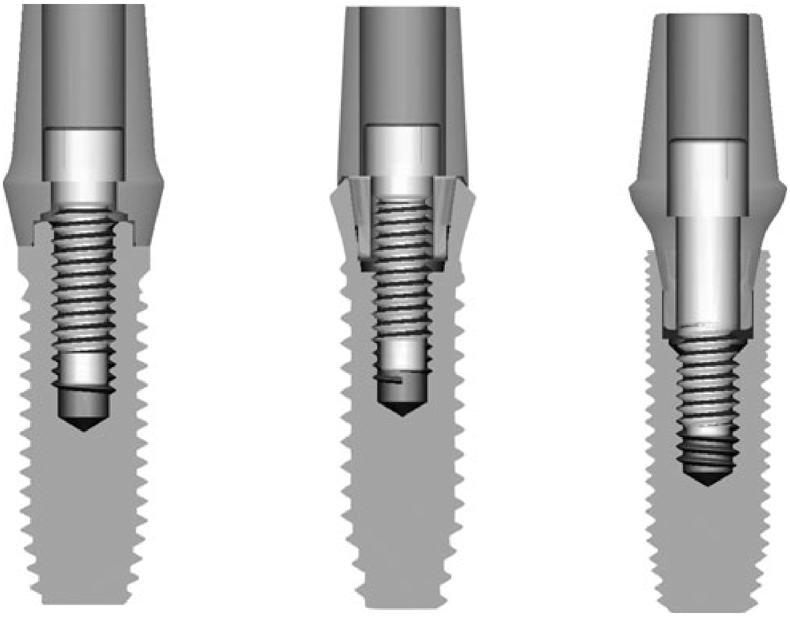

Figure 2 Three implant connection diagrams: US II (left): external-hex butt joint connection; SS II (middle): internal conical connection with 8° Morse Taper with 2.8 mm collar neck; GS II (right): internal conical connection with 11° Morse Taper.

WC/CTa and Ta to 30 Ncm torque and retightened to 30 Ncm 10 minutes later. Cyclic load was applied to each system following ISO 14801 specifications (Fig 4). A machined stainless steel jig with the matching shape of the abutment for each implant system was attached using resin temporary cement (Premier Implant Cement, Premier Dental Product Company, Plymouth, MA). An Instron machine (8872, Instron Corp., Norwood, MA) was used to apply a minimum 10 N and maximum 250 N force at a 30° angle from the long axis of the implant system at a repeated rate of 2 Hz for 1 million cycles. The cyclic loading force was applied 11 mm from the implant fixation point. After 1 million cyclic loads, abutment screw-removal torque was measured with the same digital torque meter. A total of 30 implant-abutment screw assemblies were used for the postload removal-torque measurements.

Removal-torque loss

The ratio of the removal-torque loss is calculated by the following formula to determine the efficacy of the abutment screw types and the implant connection system.

Preload loss (%) = (initial removal torque – postload removal torque)/(initial removal torque) $\times$ 100

Statistics

Mean and standard deviation was calculated for each test measurement. Wilcoxon *t*-test was used to determine the statistically significant difference for the two screws in the rotational tightening angle, compression force, removal-torque force, and preload loss ratio percent. One-way ANOVA was used to determine the statistically significant difference in the implant

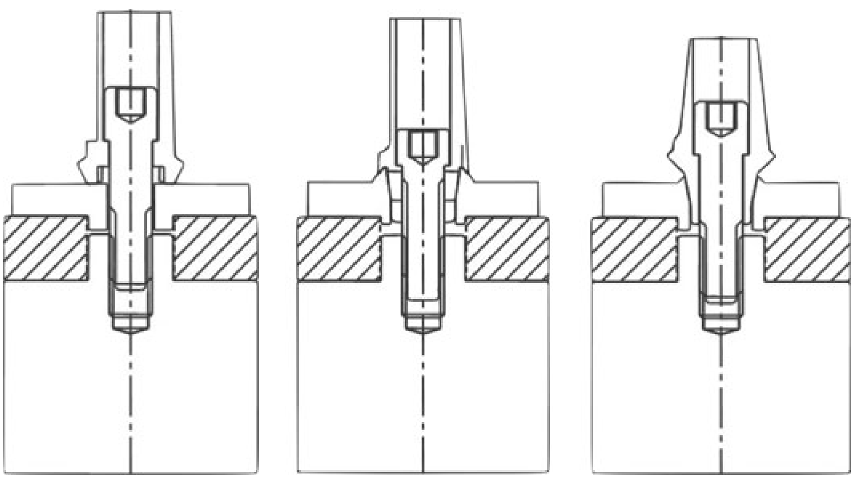

Figure 3 Schematics for compression force test apparatus. Sensors (shaded lines) were placed between the component models for US II connection (left), SS II connection (middle), and GS II connection (right).

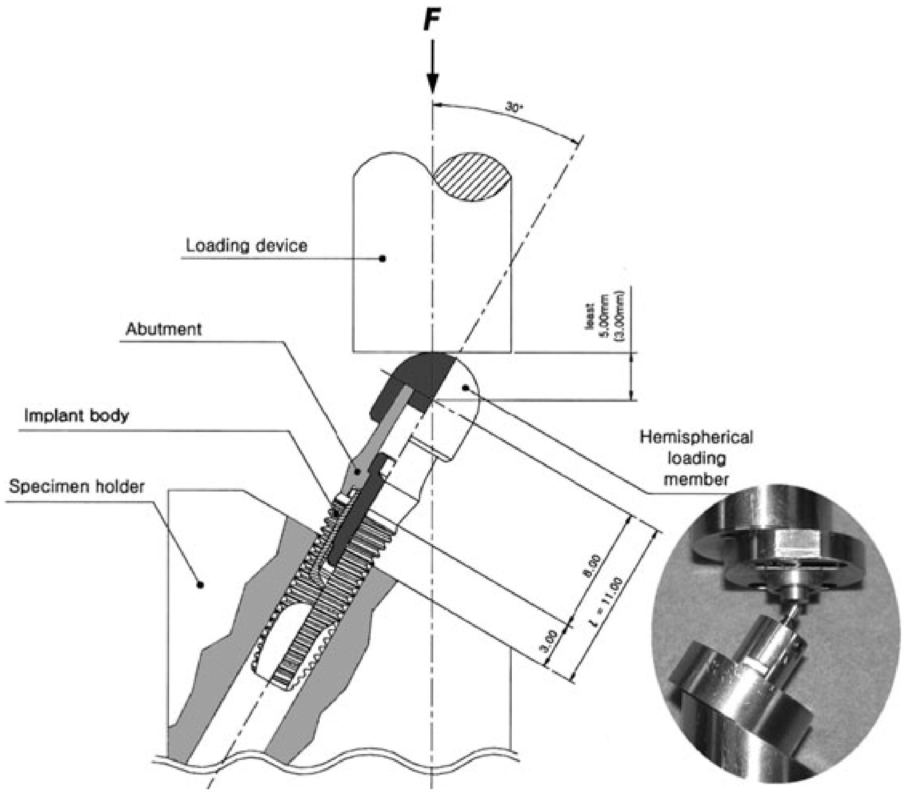

Figure 4 Cyclic load test condition.

connection systems. All statistical analysis used SPSS 12.0 (SPSS Inc., Chicago, IL).

Results

Tightening rotational angle

The mean tightening rotational angle for WC/CTa screws was approximately 10° higher than Ta screws for all three implant connection systems (Table 1), and this difference was statistically significant ($p < 0.05$). The mean tightening rotational angles for the internal conical connection of SS II and GS II were statically higher than the external-hex butt joint US II connection for both WC/CTa and Ta screws ($p < 0.05$); however, the rotational angle differences between the two internal conical connections, SS II and GS II, were not statistically significant ($p > 0.05$).

Table 1 Mean tightening rotational angle and standard deviation (degree)

Implant system	Ta screw	WC/CTa screw
US II	25.8 ± 0.7aA	35.5 ± 0.5aB
SS II	28.5 ± 0.6bA	39.0 ± 0.5bB
GS II	28.3 ± 0.7bA	38.5 ± 0.7bB

Same uppercase letters indicate no statistically significant difference in rows ($p > 0.05$).
Same lowercase letters indicate no statistically significant difference in columns ($p > 0.05$).

Compression force

The mean compression force generated by WC/CTa screws was higher than Ta screws in all three connection systems (Fig 5). The difference was statistically significant ($p < 0.05$).

The US II connection (external-hex butt joint) had a statistically significantly higher compression force than SS II or GS II (internal conical connection) systems with both WC/CTa and Ta screws ($p < 0.05$). GS II system (11° Morse Taper

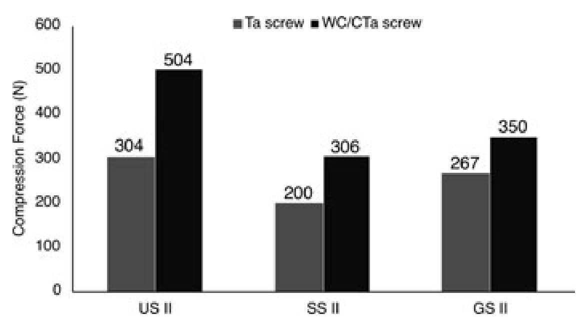

Figure 5 Mean compression force in each implant connection system with Ta and WC/CTa screws.

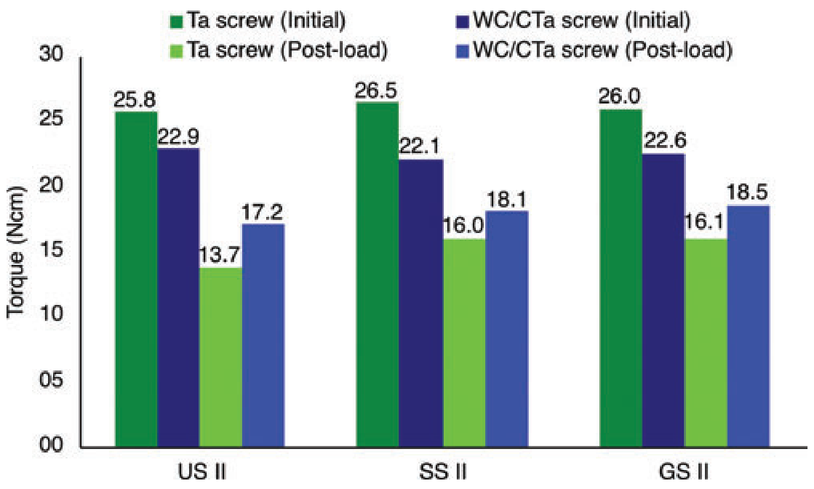

Figure 6 Mean initial and postload screw-removal torque force for three implant connection systems with Ta and WC/CTa screws.

connection) had a statistically higher compression force than SS II system (8° Morse Taper connection) with both WC/CTa and Ta screws ($p < 0.05$).

Screw removal torque and preload loss percent

The mean initial removal torque force for Ta screws was higher than WC/CTa screws in all three implant connection systems (Fig 6). This difference was statistically significant ($p < 0.05$). When comparing the implant connection systems using the same type of screw (Ta or WC/CTa), the mean initial removal torque force for all three implants systems was not significantly different ($p > 0.05$).

The mean postload removal torque force for Ta screws was lower than WC/CTa screws in all three implant connection systems. This difference was statistically significant ($p < 0.05$). The preload loss percent of screw-removal torque before and after cyclic loading was significantly higher for Ta screws than WC/CTa screws in all three implant connection systems ($p < 0.05$) (Fig 7). When comparing the preload loss percent for the implant connection systems, the external-hex butt joint (US II) had a statistically higher preload loss than the internal conical connections ($p < 0.05$); however there was no significant difference between the two internal connections ($p > 0.05$).

Discussion

The present experiment investigated the effects of screw coating and implant-abutment connection types on preload. The tungsten carbide carbon surface coating on titanium alloy (WC/CTa) abutment screws reduced the friction to provide a 10° higher rotational angle at 30 Ncm tightening torque force than the noncoated titanium alloy (Ta) screws in three implant connection systems. A 10° rotation angle difference between WC/CTa and Ta screws represented 200 N for US II (external-hex butt joint), 106 N for SS II (8° Morse Tapered internal conical connection), and 83 N for GS II (11° Morse Tapered internal conical connection) mean compression force or preload differences (Fig 5). In other words, WC/CTa screws provided greater compressive force for superior joint stability than noncoated Ta screws for all three connections. The external-hex butt joint benefited the most from screw surface coating.

Drago reported only one screw loosening in 104 single-tooth implant restorations with Gold-Tite screws (3i, Palm Beach Gardens, FL) in a 1-year follow-up period.[27] This 1% rate of screw loosening is lower than others[28,29] that reported single-tooth implant restoration screw loosening in the literature. Martin et al showed that Gold-Tite screws had a higher tightening rotation angle and greater preload than Titanium alloy screws.[19] Higher rotational angle and greater preload with WC/CTa screws in the present experiment are more likely to reduce screw loosening in clinical situations than Ta screws; however, clinical investigation is needed to confirm the postulation with WC/CTa screws.

It is interesting to note that the mean initial screw-removal torque for noncoated Ta screws was higher than for WC/CTa screws (Fig 6). This is probably explained by the fact that tungsten carbide carbon surface coating reduced the friction during tightening to provide higher preload, but it equally reduced the frictional resistance of the screw for the removal rotation, therefore resulting in lower removal torque for WC/CTa screws than Ta screws. However, the mean postload removal torque for WC/CTa screws was higher than Ta screws. The ratio of preload loss percent was statistically significantly higher with Ta screws than WC/CTa screws after cyclic loading,

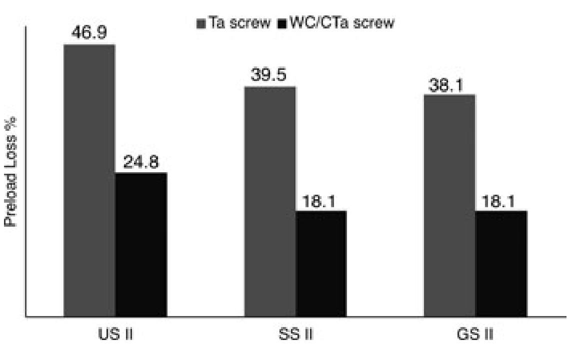

Figure 7 Preload loss percent in mean removal torque in three implant connection systems with Ta and WC/CTa screws.

indicating that WC/CTa screws were much more effective in retaining preload (Fig 7). Perhaps tungsten carbide carbon coating surface on abutment screws provided greater preload for more stable joints, thus retaining superior preload, even after 1 million cyclic loads. This superior preload maintenance of WC/CTa screws was evident in all three implant connection types.

In implant connection system comparison, frictional fit of internal conical connections contributed additional joint stability in conjunction to the abutment screw preload. The postload removal torque loss for both internal conical connection systems (SS II and GS II) was significantly less than the US II system. This shows that internal connection with Morse Tapered frictional fit is a beneficial feature for the implant-abutment joint stability to resist external loading force. Different internal Morse Tapering (8° vs. 11°) was a factor in the mean compression force, but not in the mean postload removal torque and preload loss percent. It can be speculated that different screw designs, degrees of wedging effects, implant platform designs, or combinations may have resulted in different compressive forces. Nevertheless, both frictional interference connections helped to stabilize the joint against the load and maintained the preload of the screw equally effectively since the loss of preload after the cyclic load between the two conical connections was not statistically different.

The SS II implant design had a 2.8-mm collar neck to move the implant-abutment junction away from the bone for one-stage purpose. This collar neck design made for a 2.8-mm shorter lever arm acting on the implant-abutment junction for SS II than US II and GS II in the cyclic load of the present experiment. The result of significantly higher preload loss percent for US II in comparison to SS II was somewhat expected, as the abutment screw was the only mechanism to resist the loading force in the cyclic test in US II, and the lever arm acting on the connection was also longer than SS II. But it is noteworthy that preload loss percent for GS II was statistically equivalent to SS II after the cyclic load despite the longer lever arm acting on GS II. It may be possible that a greater wedging effect was created in GS II than SS II, thus favoring a more stable joint connection to withstand the unfavorable loading condition. It may also be speculated that different implant platform designs between SS II and GS II had effects on the joint stability. The compression force of GS II was statistically higher than SS II. Further study is probably needed to investigate the influence of different Morse Tapers in implant joint connections (8° vs. 11°) and different implant platforms on the joint stability.

Based on this investigation, WC/CTa screws can be beneficial for reducing the screw-loosening problem in clinical situations. Less screw loosening can be expected with WC/CTa screw use in all three implant connection systems; particularly, US II external-hex implant connection can be more beneficial than SS II or GS II connection systems. However, the loading condition in a clinical situation is not the same as in this investigation. Loading from patient to patient can be very different, and many other factors can be important in screw loosening. Therefore, a well-controlled clinical study is warranted with WC/CTa and non-WC/CTa screws to determine the effectiveness of coating in clinical situations in preventing screw-loosening problems.

Conclusion

Within the limits of the present study, the following conclusions can be made:

1. Tungsten carbide carbon coating surface on titanium alloy (WC/CTa) screws provided a higher preload than non-coated titanium alloy (Ta) screws in all three implant connection systems.
2. Initial removal torque for Ta screws required higher force than WC/CTa screws, whereas postload removal torque for the Ta screw was lower than the WC/CTa screw. Calculated Ta screw preload loss percent was higher than the WC/CTa screws, indicating that the WC/CTa screw was more effective in maintaining preload than the Ta screw.
3. Internal conical connections were more effective in maintaining the screw preload in cyclic loads than external-hex butt joint connections.

Acknowledgments

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