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A Study of mechanical properties of oxide layer removed Co-Cr-Mo abutments

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ABSTRACT

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PURPOSE: The aim of this study was to evaluate the influence of the oxide layer removal process in the Co-Cr-Mo (CCM) abutment after casting procedure on the prosthesis settlement and screw stability. MATERIALS AND METHODS: CCM abutments of four different interface conditions (CCM-M; machined, CCM-O; oxide layer formed, CCM-B; blasted, CCM-P; polished after blasted) and gold abutment (Gold-C; Cast with type III Gold alloy) were used. The initial settling values of abutments were evaluated according to the difference of implant-abutment length when the tightening torques were applied at 5 Ncm and 30 Ncm, and the settling values of abutments caused by loading were evaluated according to the difference of implant-abutment length before and after loading with 250 N, 100000 cycle. The loss ratios of removal torque for abutment screws were evaluated according to the difference in value of removal torques under 30 Ncm tightening torque applied before and after cyclic loading. RESULTS: The CCM-P and CCM-B group showed a higher initial settling value compared with the Gold-C group ($P<.05$), while the Gold-C group showed the highest settling values caused by loading ($P<.05$) and no significant differences were observed for between CCM groups ($P>.05$). The loss ratio of removal torque values for the CCM-B, CCM-P groups did not differ significantly from that of the Gold-C group ($P>.05$). CONCLUSION: Even though the oxide layer was removed by different methods, CCM abutment with internal conical connection structure showed lower abutment settling and similar screw loosening after cyclic loading compared with gold abutment.

Key words : UCLA abutment; Gold abutment; CCM abutment; Oxide layer; Settling: Screw loosening

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Ⅰ. INTRODUCTION

Since the osseointegration was first reported by Brånemark, a high rate of success of dental implant treatment has been reported in upper full edentulous, lower full edentulous, or partial edentulous patients[1, 2]. However, in the long-term clinical results, mechanical complications of dental implants have been reported, meaning that the symptoms could include loosening or fracture of abutment screws and crown fracture[3~5]. Kim et al6 reported that settling can occur in various structures of dental implants, however, it occurs most often in the two piece abutment of the internal conical connection structured implant system. In addition, they claimed that screw loosening due to settling could be reduced through retightening of the abutment screw.

The UCLA abutment is used as an implant prosthesis through the prosthesis fabrication process, including wax up, burn out, casting, and porcelain build up; such various processes can influence long term stability of the implant prosthesis[7, 8]. Barbosa et al[9] reported that vertical fitness of fixture and abutment may differ, depending on the accuracy of the prosthesis-related laboratory work and prosthesis misfit may be directly related to loosening of abutment screws[10]. With the international gold price rising in the second half of the 2000s, costs for use of gold UCLA abutment were incurred; as a result, there is a need for development of another abutment with high clinical utilization for replacement of the gold UCLA abutment. This has caused interest in the Co-Cr-Mo (CCM) alloy, which is being used in a clinical UCLA abutment. CCM alloy, with its excellent mechanical properties and biocompatibility has been used mainly as material of orthopedic joint implants[11, 12]. Co-Cr-based alloy, similar to CCM alloy, was also used as material of the fixture or prosthesis in dental implants. A study by Proussaefs and Lozada[13] reported no agitation or abnormal symptoms in the blade type implant with a Co-Cr-based vitallium alloy for a period of 21 years and osseointegration remained stable. In addition, Teigen and Jokstad[14] reported that the Co-Cr based alloy did not influence success rates and survival of surgical implant in an approximately 10-year-old implant supported fixed prosthesis when compared to type III gold alloy. When CCM alloy is utilized as the UCLA abutment material, the abutment is produced, casted in a non-precious metal alloy, such as Ni-Cr- based or Co-Cr-based alloy. However, non-precious metal alloy creates a more non-aesthetic and thicker oxide layer than gold UCLA abutment on the entire surface, including abutment connection in the process of a high-temperature laboratory, such as burning out, casting, and porcelain building up. This oxide layer may not only be the cause of misfit and lowering aesthetics of the prosthesis, but can also cause a change in hardness. Methods for removal of the oxide layer can be largely divided according to chemical methods and mechanical methods. In general, the oxide layer generated from the gold alloy is removed using a chemical method, such as acid pickling; on the other hand, oxide layer from non-precious metal alloy is mainly blasted with alumina or glass beads, or removed using a mechanical method, such as polishing after blasting[15]. Removal of the oxide layer in CCM abutment connection parts using a mechanical method influences the abutment, the abutment screw, and the contact surface between the fixture and abutment, and abutment settling or abutment screw loosening may then be affected. However, there are no references about the guidelines how to remove an oxide layer in the clinical situation. These procedures are dependent on the experience of the technician until now. Therefore, the aim of this study was to evaluate the influence of the various oxide layer removal processes in the Co-Cr-Mo (CCM) abutment after casting procedure on the prosthesis settlement and screw stability, and suggest the most effective method to remove the oxide layer of CCM abutment to clinician.

Ⅱ. MATERIALS AND METHODS

1. Properties of alloys formed oxide layer

A CCM (Biodur® CCM, Carpenter, Reading, PA, USA), which is used in abutment alloy material, was fabricated by machining in the form of a disc to diameter 6 mm, thickness 1 mm. The oxide layer of the CCM alloy disc was treated through the process of burn out under non-precious metal alloy casting conditions, cooling at room temperature, and the oxide layer was produced only through a porcelain firing schedule without porcelain build up (n=5, in each group). For removal of the oxide layer, blasting with 50 ㎛ glass beads (Rolloblast, Renfert GmbH, Hilzingen, Germany) with 5 kgf/㎠ pressure or light polishing with cotton wheel spread with rouge was performed until discoloration was removed. Gold alloy was produced by machining in the form of a disc of the same size using Au-Pd-Pt alloy (Au: 60~65%, Pd: 20~25%, Pt: 10~15%, Osstem implant Co., Ltd., Busan, Korea), which was the same as the abutment material, in order to form the oxide layer; a burn out schedule for the precious metal alloy casting was established, followed by quenching. Alloy disc samples used in the experiment are shown in the following Fig. 1(n=5, in each group).

CCM alloy was set for the machining phase (CCM-M), the phase in which the oxide layer is generated after burn out and porcelain firing schedule (CCM-O), the phase involving blasting for removal of the oxide layer created (CCM-B), and the phase involving polishing after blasting (CCM-P), while the gold alloy group is set for the machining phase (Gold-M) and the phase in which the burn out schedule is worked out (Gold-C).

The surface of the CCM alloy disc (CCM-O) on which the oxide layer was produced was observed by Scanning Electron Microscope (JSM- 6480 LV, JEOL Ltd., Tokyo, Japan) to 3000-fold and 10,000-fold magnification, and

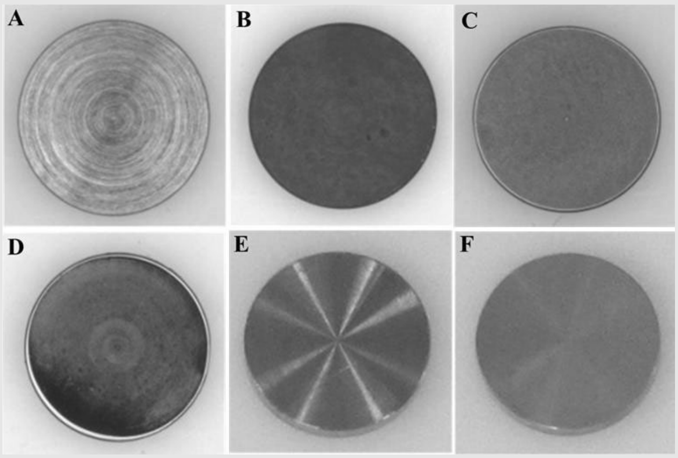


Fig. 1. Disc specimens for oxide layer analysis. A; CCM-M group (machined), B; CCM-O group (oxide layer formed), C; CCM-B group (blasted), D; CCM-P group (polished after blasted), E; Gold-M group (machined), F; Gold-C group (burned out). N=5, in each group.

surface components were analyzed by Energy dispersive x-ray spectroscopy (7573, Oxford instruments plc., Oxfordshire, England). The surface hardness of the CCM alloy was measured at three spots on the sample (n=5) using a Rockwell hardness tester (O.M.A.G, AFFRI Co., ltd., Induno Olona, Italy). On the other hand, since measurement of the gold alloy disc was impossible using a Rockwell hardness tester due to the low hardness values, it was compared with the resulting value of the CCM alloy disc by converting to Hardness Rockwell C (HRC) unit after measurement using a Vickers hardness tester (HM-122, Mitutoyo Co., ltd., Kawasaki, Japan).

2. Mechanical stability of abutments

A fixture with an internal conical connection structure of 11°(TS II Fixture, Osstem Implant Co., Ltd., Busan, Korea) was used, CCM alloy abutment (TS NP-Cast Abutment, Osstem Implant Co., Ltd., Busan, Korea), gold alloy abutment (TS GoldCast Abutment, Osstem Implant Co., Ltd., Busan, Korea), and the abutment screw produced by the same manufacturer were used. The CCM alloy abutment was produced by machining with a standardized size and shape, as shown in B of Fig. 2. The reason why the CCM abutment was produced by machining was that casting of non-precious metal alloy was formed thick oxide layer and the removal of investment material made the irregularity in upper portion of abutment, it was possible to make errors in the measured value. Gold alloy abutment was assembled with casting part by plastic pattern and connecting part by machining. The casting part was casted in type III gold alloy (BAKER444, Heesung Catalyst Co., Seoul,

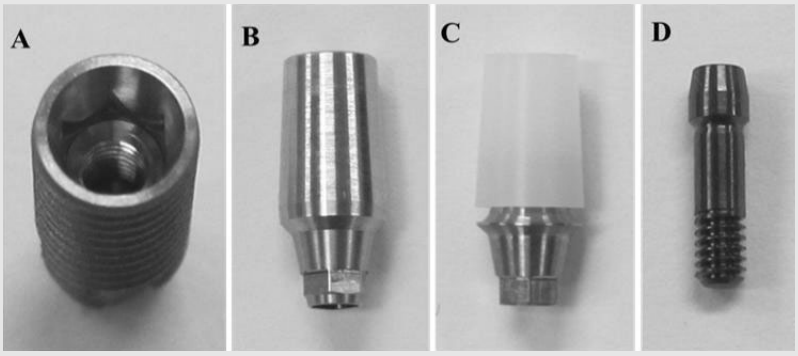


Fig. 2. Internal conical connection implant specimens for mechanical testing. A; Fixture (ø 4.0 mm, L 11mm Titanium Grade 4), B; Prepared CCM abutment (ø 4.5 mm, Gingival height 1.0mm, Co-Cr-Mo alloy), C; UCLA abutment (ø 4.5 mm, Gingival height 1.0mm, gold alloy). D; Abutment screw (Ti-6Al-4V).

Korea) with the same dimensions as the CCM alloy abutment (Fig. 2). CCM Abutment was conducted porcelain firing to implement a process to create the maximum oxide layer on the normal usage mode, and the control group of gold abutment was conducted up to the casting stage, which creates minimum oxide layer that can be compared with optimum usage condition of gold abutment.

Burn out and porcelain firing schedule for the CCM abutment was worked out in the same way as for the sample disc specimens, while blasting the CCM abutment was worked out to the abutment connection area and entry hall of the abutment screw (Fig. 3).

Abutment settling was evaluated by dividing into the amount of the initial settling caused by tightening torque applied to the abutment screw and the amount of settling by cyclic loading. The initial settling by tightening torque was calculated for measurement of the difference in the length of abutment-implant combination when tightening torque was applied at 5 Ncm and 30 Ncm. The tightening torque was measured using a digital torque gauge (MGT12, MARK-10 Co., Copiague, NY, U.S.A), while the total length of the implant was measured using a digital micrometer (No.293-666N, Mitutoyo Co., ltd., Kawasaki, Japan). For measurement of the removal torque loss ratio of the abutment screw, the abutment in each group was combined with the fixture, and removal torque was measured after application of 30 Ncm tightening torque to the abutment screw. Then, abutment was combined with the tightening torque of 30 Ncm again, and removal torque was measured again after cycling loading applied by repeating 100,000 times to 14 Hz under the load from Min. 25 N to Max. 250 N. Calculation of the removal torque loss ratio of the abutment screw by cyclic loading was as follows:

Removal torque loss ratio of abutment screw (%)
= (Removal torque value of abutment screw
after cycling loading
/ Removal torque value of abutment screw

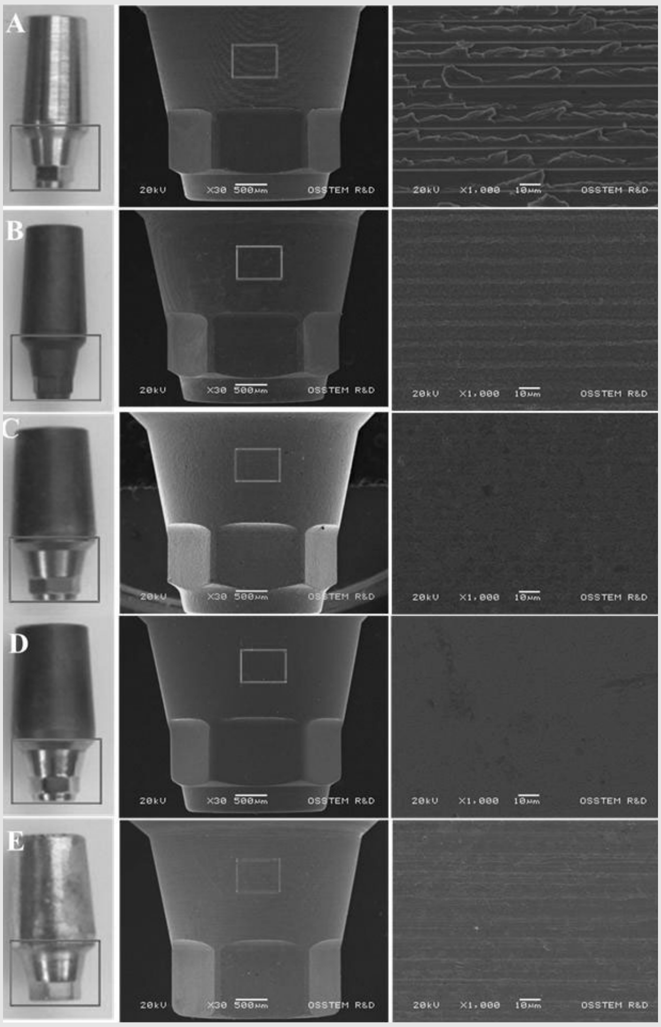


Fig. 3. Images of abutment specimens for mechanical testing. (left to right; abutment, abutment interface (magnification ×30), abutment interface surface (magnification×1,000)) A; CCM-M group; machined. B; CCM-O group; oxide layer formed. C; CCM-B group; blasted. D; CCM-P group; polished after blasted. E; Gold-C group; cast with type III gold alloy and acid pickling. (n=7 in each group)

before cycling loading) x 100

3. Statistical analysis

SSPS (Ver.12.0, Standard package Inc., Chicago, IL, USA) was used to confirm the statistical reliability of each of the experimental results in 95% confidence level. The Shapiro-Wilks Normality Test was performed. The measured value did not conform to normality, the Kruskal-Wallis test was performed, and the Mann-Whitney analysis was also performed for post-hoc comparison between groups.

Ⅲ. RESULTS

An SEM observation photograph of the thick oxide layer created on the surface of the CCM alloy through a process of burn out and porcelain firing schedule is shown in Fig. 4. In the EDS analysis, approximately 35% of oxygen was measured with one of the elements on the oxide layer created at the weight ratio; compared to the other elements, cobalt elements were decreased but chrome elements were increased, respectively. Table 1 shows the weight ratio of

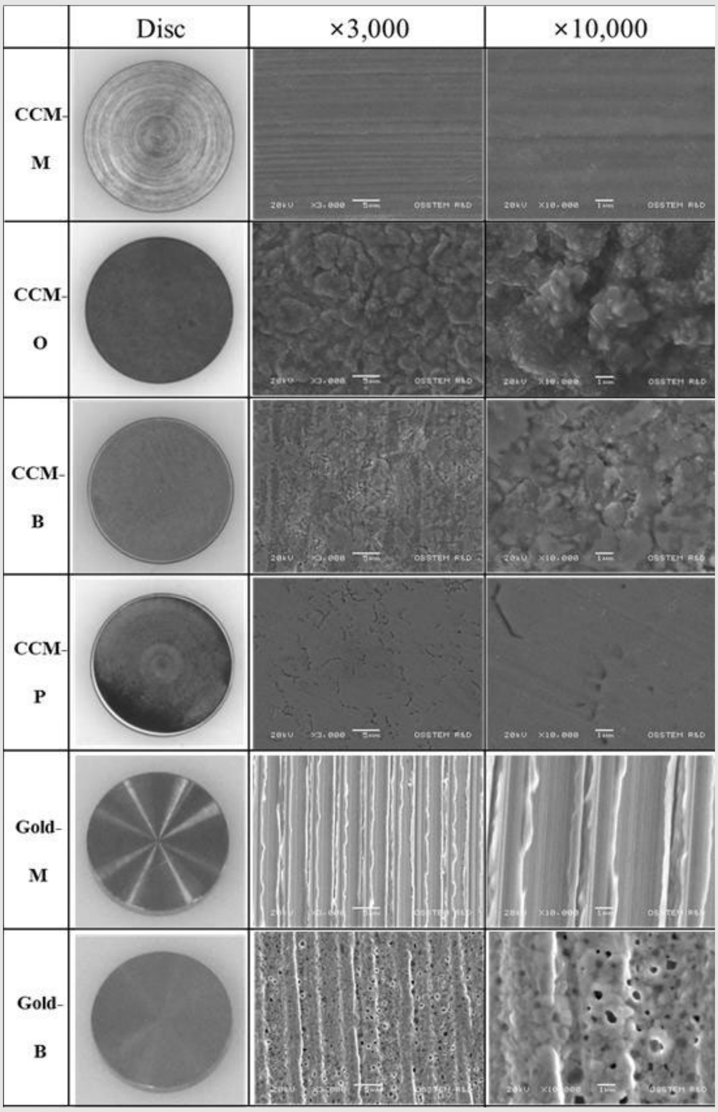


Fig. 4. SEM images of the surface oxide layer after burn out and porcelain firing process of CCM and gold alloy. CCM-M group (machined), CCM-O group (oxide layer formed), CCM-B group (blasted), CCM-P group (polished after blasted), Gold-M group (machined), Gold-C group (burned out).

the CCM alloy surface elements before and after creation of the oxide layer.

The measured hardness values are shown in Table 2. The measured hardness values in all CCM alloy groups were larger than in the gold alloy group (P<0.05). In the CCM alloy, the CCM-M group showed significantly higher values than the rest of the groups, while the Gold-M group showed significantly higher values than the Gold-C group after the burn out in gold alloy (P<0.05). No significant difference in measured hardness values was observed among the CCM-O group, CCM-B group, and CCM-P group (P>0.05).

Table 1. Weight (%) variation of surface elements after burn out, porcelain firing and polishing process for CCM alloy

	O	Co	Cr	Mo	Mn	Si	C	Total
CCM-M	-	57.33	24.49	4.93	1.11	0.61	11.53	100
CCM-O	35.02	14.92	40.86	1.28	3.47	0.57	3.88	100
CCM-B	12.34	51.12	23.84	5.40	0.83	2.59	3.87	100
CCM-P	4.34	61.44	21.56	6.85	0.63	1.46	3.27	100

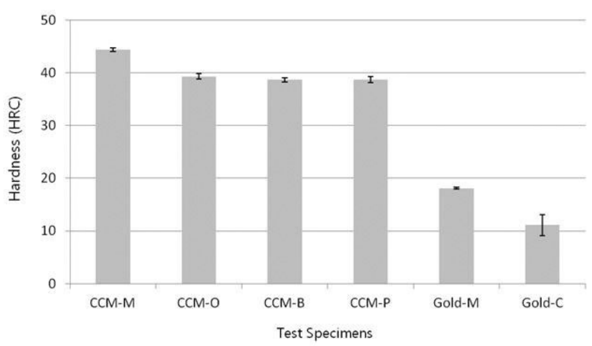
CCM-M group (machined), CCM-O group (oxide layer formed), CCM-B group (blasted), CCM-P group (Polished after blasted).

Table 2. Mean values and standard deviations (SD) of hardness

Test Specimen	n	Mean ± SD* (HRC)
CCM-M	5	44.4 ± 0.3a
CCM-O	5	39.3 ± 0.5b
CCM-B	5	38.7 ± 0.4b
CCM-P	5	38.7 ± 0.6b
Gold-M	5	18.1 ± 0.7c
Gold-C	5	11.1 ± 2.0d

* Same letters indicate values that were not statistically different (p>0.05).
CCM-M group (machined), CCM-O group (oxide layer formed), CCM-B group (blasted), CCM-P group (Polished after blasted), Gold-M group (machined), Gold-C group (burned out). The values were Hardness Rockwell C (HRC).

Graph 1. Mean values of hardness



CCM-M group (machined), CCM-O group (oxide layer formed), CCM-B group (blasted), CCM-P group (Polished after blasted), Gold-M group (machined), Gold-C group (burned out). The values were Hardness Rockwell C (HRC).

Data on the amount of initial abutment settling by tightening torque, abutment settling by cyclic loading and removal torque loss ratio are shown in Table 3. The largest quantity of CCM abutment was observed in the CCM-P group, while the CCM-B group, the CCM-M group, and the CCM-O group showed a small amount of initial settling in a row ($P<0.05$).

For gold alloy abutment, the amount of settling after cyclic loading was larger than in all CCM abutment groups ($P<0.05$). No significant difference in CCM alloy was observed between the groups ($P> 0.05$). The most significant removal torque loss ratio was observed in the CCM-O group ($P <0.05$). No significant differences were observed among the CCM-M group, the CCM-B group, the CCM-P group, and the Gold-C group ($P> 0.05$).

Ⅳ. DISCUSSION

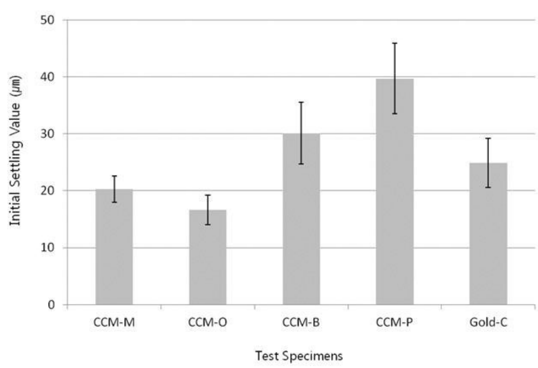
According to the results of this study, a thick oxide layer was formed by the prosthesis manufacturing process of burning out and porcelain firing on the CCM abutment. If analyzing the components of the surface oxide layer, approximately 35% of the oxygen element

Table 3. Mean values and standard deviations (SD) of abutment settling and removal torque

Group	Initial abutment settling by tightening torque (㎛)	Abutment settling after cyclic loading (㎛)	Removal torque loss Ratios(%)
CCM-M	20.3 ± 2.3a	3.7 ± 1.4a	19.6 ± 4.8a
CCM-O	16.6 ± 2.6b	3.3 ± 1.1a	26.2 ± 1.5b
CCM-B	30.1 ± 5.4c	3.6 ± 1.3a	17.8 ± 4.4a
CCM-P	39.7 ± 6.2d	3.4 ± 0.5a	19.3 ± 4.6a
Gold-C	24.9 ± 4.3a	15.4 ± 5.5b	19.6 ± 2.8a

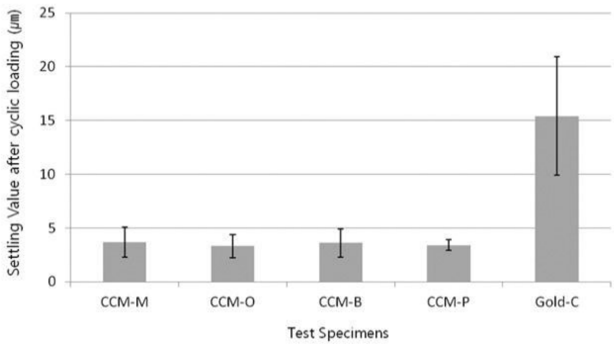
* Same letters indicate values that were not statistically different ($p>0.05$). CCM-M group (machined), CCM-O group (oxide layer formed), CCM-B group (blasted), CCM-P group (Polished after blasted), Gold-C group (Cast with type III Gold Alloy). N = 7 in each group.

Graph 2. Mean values of initial abutment settling by tightening torque



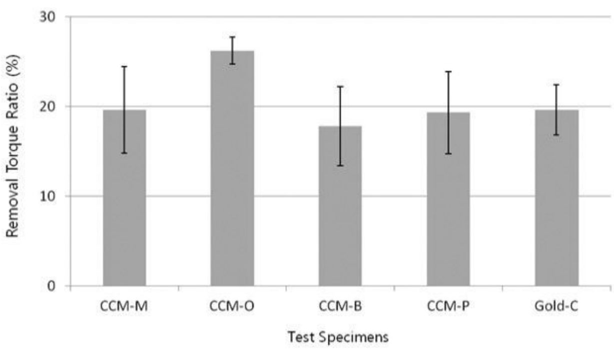
CCM-M group (machined), CCM-O group (oxide layer formed), CCM-B group (blasted), CCM-P group (Polished after blasted), Gold-C group (Cast with type III Gold Alloy). N = 7 in each group.

Graph 3. Abutment settling after cyclic loading



CCM-M group (machined), CCM-O group (oxide layer formed), CCM-B group (blasted), CCM-P group (Polished after blasted), Gold-C group (Cast with type III Gold Alloy). N = 7 in each group.

Graph 4. Removal torque loss Ratios



CCM-M group (machined), CCM-O group (oxide layer formed), CCM-B group (blasted), CCM-P group (Polished after blasted), Gold-C group (Cast with type III Gold Alloy). N = 7 in each group.

was measured. Based on this, it can be seen that some elements of the CCM alloy elements generated the oxide of certain elements on the surface due to reaction with oxygen at high temperatures. In particular, based on the significant increase of chrome elements compared to the elemental composition, it may be guessed that they are chrome oxides, however, additional studies are needed in order to determine the exact component configuration of oxide. Regarding changes in the surface hardness of alloy due to burning out and porcelain firing schedule, approximately 11.5% of decreases occurred in the case of CCM alloy and approximately 38.7% of the decreases in hardness occurred in the case of gold alloy after burning out. These changes in hardness appear to be due to changes in the mechanical properties of the metal itself as well as formation of the oxide layer. At first design in this study, we used casting CCM abutment which is clinically used. But there was very thick oxide layer on top portion of abutment after casting. Therefore, it was impossible to measure the settlement length correctly and the measurement of abutment length itself was occurred the deviation. According to these reasons, machining one-body CCM abutments were prepared to reduce the experimental error by specimen itself. In contrast, the gold UCLA abutment was not formed the oxide layer on the abutment.

Degradation of alloy hardness may occur when the softening heat treatment might be effective through the process of burn out, porcelain firing temperature, and cooling in the prosthesis manufacturing process.[15] Based on the measured value of hardness, CCM alloy abutment used in making implant prosthesis is approximately four times greater than gold alloy abutment, which may be a factor influencing the mechanical properties of the implant prosthesis. The amount of the initial abutment settling by the tightening torque measured by 30 Ncm means that the occlusal contact point of the prosthesis finished in the process of making the prosthesis can be lowered at the time of mounting the prosthesis in the mouth. When tightening torque is applied, the amount of initial settling in the CCM abutment without burning out and porcelain firing schedule was the same level as that of the gold alloy abutment. However, larger abutment initial settling occurred in the group with blasting and removal of the oxide layer than in the group with machining state; in addition, much greater initial settling occurred in the group in which polishing up was performed after blasting. This result means that performance of more work during the process for removal of the oxide layer may cause a significant decrease in accuracy in the connection area of the abutment. Meanwhile, regarding the abutment settling by cyclic loading, no significant difference was observed between groups of the CCM abutment. The measured values of approximately 3-4 ㎛ were negligible, meaning that in the case of the CCM abutment, the amount of settling by occlusal loading is insignificant after the initial abutment settling has occurred in the tightening torque measured by 30 Ncm. However, in the case of the gold alloy abutment, approximately 15 ㎛ of settling after cyclic loading occurred, which was three or four times more than that of the CCM abutment. These results indicate that the main factors of initial settling by the tightening torque were due to poor precision in the abutment connection area by removal of the oxide layer, and settling by cyclic loading was mainly influenced by mechanical properties of the abutment material. The removal torque loss ratio of the abutment screw refers to the possibility of screw loosening. However, a loss of preload by micro-movement can cause screw loosening, except the abutment settling.[16, 17] In this study, although no difference in the amount of settling by cyclic loading was observed between the CCM-O group with oxide layer and the CCM-M group, a significantly large difference was observed in the aspect of the removal torque loss ratio of the abutment screw. It is considered that loading with the lateral component was generated because micro-bending of implant combination by loading or jig of testing samples is not possible, and perfect contact of implant samples may cause micro-movement, although cyclic loading was applied to be parallel to the long axis. Thus, it is believed that preload loss could occur due to micro-movement increase in the CCM-O group with a weak oxide layer; however, conduct of additional studies will be needed for investigation of this hypothesis. The aim of this study was to perform a short-term evaluation in view of mechanical properties. Later, apart from this mechanical evaluation, with long-term evaluation, ongoing experimental and clinical studies for soft tissue, bone reaction, etc. in the CCM abutment may be necessary in terms of biological perspective.

Ⅴ. CONCLUSION

Within the limitations of this study, even though the oxide layer of the CCM abutment with the structure of the internal conical connection was blasted using glass beads or removed by cotton wheel polishing after blasting, the settling phenomenon of prosthesis after cyclic loading was less than that of the gold abutment. In addition, there was no significant difference in abutment screw stability. Even though the oxide layer was removed by different methods, CCM abutment with internal conical connection structure showed lower abutment settling and similar screw loosening after cyclic loading compared with gold abutment.

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