치의과학박사 학위논문

Axial displacement of CAD/CAM customized abutments in internal-connection type implants

내측연결형 임플란트에서 반복하중에 따른 CAD/CAM 지대주의 수직침하현상

2018 년 8 월

서울대학교 대학원

치의과학과 치과보철학 전공

이 유 승

Axial displacement of CAD/CAM customized abutments in internal-connection type implants

지도교수 허 성 주

이 논문을 이유승 박사학위논문으로 제출함

2018 년 4 월

서울대학교 대학원
치의과학과 치과보철학 전공
이 유 승

이유승의 박사학위논문을 인준함

2018 년 6 월

위 원 장 _____________ (인)

부 위 원 장 _____________ (인)

위 원 _____________ (인)

위 원 _____________ (인)

위 원 _____________ (인)

- ABSTRACT -

Axial displacement of CAD/CAM customized abutments in internal-connection type implants

Yuseung Yi, D.D.S., M.S.D

Department of Prosthodontics, Graduate School, Seoul National University

(Directed by Professor Seong-Joo Heo, D.D.S., M.S.D., Ph.D.)

Purpose: The purpose of this *in vitro* study was to compare the axial displacements, the reduction rate of removal torque values (RTVs) and the tensile forces necessary to dislodge the CAD/CAM customized abutments and prefabricated abutments after cyclic loading from internal-connection type implants.

Materials and methods: Four types of implant-abutment assembly groups were prepared (Total 28, n = 7 in each group): Astra OsseoSpeed^{TM} TX4.0S X 11 mm (ASTRA TECH, Dentsply IH AB, Mölndal, Sweden) and TiDesign^{TM} abutments 3.5/4.0 (ϕ4.5 G/H 1.5 VH 9.0) fabricated by the same manufacturer with the implant (Group 1, control), Astra OsseoSpeed^{TM} TX4.0S X 11 mm and CAD/CAM customized compatible abutments manufactured by the other CAD/CAM laboratory (MyPLANT^{TM}, Raphabio, Seoul, Korea) designed to the form of TiDesign^{TM} abutments 3.5/4.0 (ϕ4.5 G/H 1.5 VH 9.0) (Group 2), Osstem TS II R4.0 X 10 mm and CAD/CAM abutments manufactured by the CAD/CAM milling center of the same company with the implant (OSSTEM IMPLANT, Seoul, Korea) (Group 3) and Dentium Implantium 4.0 X 10 mm with CAD/CAM abutments manufactured by the CAD/CAM milling center of the same company with the implant (DENTIUM IMPLANT, Seoul, Korea) (Group 4). Cyclic loading was applied to implant-abutment assemblies at 150 N with a frequency of 3 Hz. The amount of axial displacement, the reduction rate of removal torque values (RTVs) and the tensile removal force to dislodge the abutments were measured after cyclic loading. Mixed model analysis was conducted to determine statistically significant effects of cyclic loading on the axial displacement of the implant-abutment assemblies. To evaluate differences among the 4 groups, Tukey's Honestly Significant Difference (HSD) method was applied. The Wilcoxon signed-rank test was conducted to compare before and after values within each group, and the Kruskal-Wallis and Mann-Whitney tests were used to compare the RTV reduction rates before and after cyclic loading and the tensile removal force after cyclic loading between the groups. Pearson correlation analysis was performed to analyze the correlation between axial displacement value, RTV reduction rate and tensile removal torque.

Results: After 1 million cyclic loadings, axial displacement occurred in all groups (-9.46 ± 3.37 μm). The value was - 9.0 ± 3.5 μm in group 1, - 10.6 ± 4.3 μm in group 2, -8.9 ± 2.9 μm in group 3 and - 9.4 ± 3.2 μm in group 4, and no significant difference was found between the prefabricated abutment and the CAD/CAM abutment. In all groups, the RTVs after cyclic loading were significantly lower than those before cyclic loading ($P \leq .05$). The RTV reduction rate after cyclic loading was 46.9 ± 8.2 % in group 1, 60.3

± 3.4 % in group 2, 52.1 ± 5.5 % in group 3 and 55.7 ± 8.6 % in group 4. The RTV reduction rate after cyclic loading was lowest in group 1 and highest in group 2, with statistically significant difference only between these two groups ($P \leq .05$). The tensile removal force after cyclic loading was 46.8 ± 11.2 N in group 1, 52.9 N ±10.4 N in group 2, 47.4 ± 7.7 N in group 3 and 50.5 ± 6.8 N in group 4. The overall mean tensile removal force was 49.4 ± 9.0 N and no significant difference was observed. Pearson correlation analysis revealed a significant correlation between axial displacement value, RTV reduction rate and tensile removal force after 1 million cyclic loadings at the 0.01 level.

Conclusions: No significant difference was found between the prefabricated abutments and the CAD/CAM abutments in the value of axial displacement, however, a significantly higher RTV reduction rate after cyclic loading was observed in CAD/CAM abutments manufactured by the other CAD/CAM laboratory. Axial displacement occurred in all groups and it was significantly correlated to the RTV reduction rate and the value of tensile removal force. After 1 million cyclic loading, even after the abutment screws were removed, all the abutments were sustained in implants, however, when the tensile removal force was applied, all the abutments displaced from the implants.

Keywords : internal type implant, CAD/CAM abutment, axial displacement, removal torque value, tensile removal force

Student Number : 2015-31249

CONTENTS

I. INTRODUCTION

The computer-aided design/computer aided manufacturing (CAD/CAM) system, which has been used in various restorative treatments ranging from a simple prosthesis to extensive implant prostheses, offers the advantage of ensuring constant results and productivity without casting errors.[1] In particular, the use of CAD/CAM in the manufacture of customized abutments can reproduce the anatomically ideal abutment shape and produce prostheses with a more aesthetic and natural emergence profile at the gingival region.[2] In addition, the definitive prosthesis can be made to have an ideal thickness, and the use of parallel prosthesis insertion grooves is facilitated by the ease of manufacturing a fixed prosthesis without reducing the retentive force.[3,4] However, vertical and horizontal misfit between the implant fixture and abutment may result in loosening or fracture of the screws or other components and, in severe cases, osseointegration failure.[5] The implant fixture and its superstructure should be precisely fitted so that proper stress distribution across the fixture is achieved during the application of masticatory force and an appropriate biological response of the soft tissue around the implant is induced.[6]

The internal connection design gives better mechanical stability than the external connection design.[7] Some studies have reported more reliable connection stability with internal-type rather than external-type implants.[7] The internal-type implants have been reported to have low levels of bacterial leakage, which is a risk factor for peri-implantitis and peripheral bone loss.[8] Thus, internal-type implants have become widely used for these reported advantages. Clinically, however, it has been often encountered the underocclusion phenomenon at the check-up appointment with patients after superstructure delivery of the internal-type implants.[9] Axial displacement is a unique feature of the internal-type implant. The abutment with internal connection type lacking a structure for vertical settling could sink axially into the inner surface of the implant.[7,9]

Currently, although a large number of CAD/CAM customized abutments are produced, there are few studies and long-term clinical results conducted on their precision or stability. Therefore, it is necessary to predict the behavior of the CAD/CAM abutments in internal-type implants. The purpose of this study was to compare CAD/CAM customized abutments with prefabricated abutments, and to compare the CAD/CAM abutments manufactured by the CAD/CAM milling center of the same company of implants with the CAD/CAM abutments manufactured by the other CAD/CAM laboratory. In this study, internal-type implants and prefabricated abutments or CAD/CAM customized abutments were assembled to be measured the axial displacements, the reduction rate of removal torque values (RTVs) and the tensile forces necessary to dislodge the abutments from the implants after vertical cyclic loading.

II. MATERIALS AND METHODS

Preparation of Implants and Abutments

Four types of implant-abutment assembly groups were prepared and a total of 28 assemblies were included, seven for each group. The implant-abutment assemblies used in each group were as follows (Table 1).

Table 1 The implants and abutments used in each group

	Implant	Abutment
 **Group 1**	Astra OsseoSpeed™ TX4.0SX11mm (ASTRA TECH, Dentsply IH AB, Mölndal, Sweden)	TiDesign™ abutment 3.5/4.0 (ϕ4.5 G/H 1.5 VH 9.0) (ASTRA TECH, Dentsply IH AB, Mölndal, Sweden)
 **Group 2**	Astra OsseoSpeed™ TX4.0SX11mm (ASTRA TECH, Dentsply IH AB, Mölndal, Sweden)	CAD/CAM customized abutment, the form of TiDesign™ 3.5/4.0 (MyPLANT™, Raphabio, Seoul, Korea)
 **Group 3**	Osstem TS II R4.0X10mm (OSSTEM IMPLANT, Seoul, Korea)	CAD/CAM customized abutment, the same superstructure form with TiDesign™ abutment 3.5/4.0 (ϕ4.5 G/H 1.5 VH 9.0) (SmartFit™, OSSTEM IMPLANT, Seoul, Korea)
 **Group 4**	Dentium Implantium 4.0X10mm (DENTIUM IMPLANT, Seoul, Korea)	CAD/CAM customized abutment, the same superstructure form with TiDesign™ abutment 3.5/4.0 (ϕ4.5 G/H 1.5 VH 9.0) (DENTIUM IMPLANT, Seoul, Korea)

In group 1, Astra OsseoSpeed^{TM} TX4.0S X 11 mm (ASTRA TECH, Dentsply IH AB, Mölndal, Sweden) with an internal hex connection and TiDesign^{TM} abutments 3.5/4.0 (ϕ4.5 G/H 1.5 VH 9.0) fabricated by the same manufacturer was used as the control. In group 2, the same implants as group 1 were used and CAD/CAM compatible abutments fabricated by the other CAD/CAM laboratory (MyPLANT^{TM}, Raphabio, Seoul, Korea) designed to the form of TiDesign^{TM} abutments 3.5/4.0 (ϕ4.5 G/H 1.5 VH 9.0) were connected. In group 3 and 4, CAD/CAM abutments manufactured by the CAD/CAM milling center of the same company with the implants were connected: Osstem TS II R4.0 X 10 mm with CAD/CAM abutments manufactured by SmartFit^{TM}, OSSTEM IMPLANT (OSSTEM IMPLANT, Seoul, Korea) and Dentium Implantium 4.0 X 10 mm with CAD/CAM abutments manufactured by DENTIUM milling center (DENTIUM IMPLANT, Seoul, Korea) were used respectively. Since all three companies did not have the same length of implants, the most similar length of implants were chosen among three companies. All implants were conical-hex internal connection with 11° Morse taper. All CAD/CAM abutments were designed in the same form of TiDesign^{TM} abutments 3.5/4.0 (ϕ4.5 G/H 1.5 VH 9.0) in group 1 and were manufactured by CNC milling of prefabricated grade 5 titanium cylinder (Fig. 1, Fig. 2).

(a) (b) (c) (d)

Fig. 1 The abutment design of each group. (a) Prefabricated abutment: TiDesign™ abutment 3.5/4.0 (ϕ4.5 G/H 1.5 VH 9.0) (ASTRA TECH, Dentsply IH AB, Mölndal, Sweden), **(b)** CAD/CAM customized abutment, the form of TiDesign™ 3.5/4.0 (ϕ4.5 G/H 1.5 VH 9.0) (MyPLANT™, Raphabio, Seoul, Korea), **(c)** CAD/CAM customized abutment, the same superstructural form with TiDesign™ 3.5/4.0 (ϕ4.5 G/H 1.5 VH 9.0) (SmartFit™, OSSTEM IMPLANT, Seoul, Korea), **(d)** CAD/CAM customized abutment, the same superstructure form with TiDesign™ 3.5/4.0 (ϕ4.5 G/H 1.5 VH 9.0) (DENTIUM IMPLANT, Seoul, Korea)

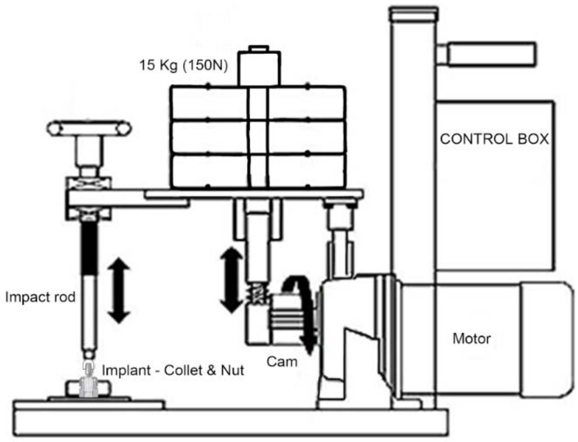
(a) (b) (c)

Fig. 2 The CAD images of CAD/CAM customized abutments. (a) CAD/CAM customized abutment used in group 2, the form of TiDesign™ 3.5/4.0 (ϕ4.5 G/H 1.5 VH 9.0) (MyPLANT™, Raphabio, Seoul, Korea), (b) CAD/CAM customized abutment used in group 3, the same superstructural form with TiDesign™ 3.5/4.0 (ϕ4.5 G/H 1.5 VH 9.0) (SmartFit™, OSSTEM IMPLANT, Seoul, Korea), (d) CAD/CAM customized abutment used in group 4, the same superstructure form with TiDesign™ 3.5/4.0 (ϕ4.5 G/H 1.5 VH 9.0) (DENTIUM IMPLANT, Seoul, Korea)

Cyclic Loading Apparatus

The same cyclic loading device (Hatis, Hwasung, Korea) designed to simulate vertical cyclic loads similar to human masticatory force used in an *in* vitro study of interchangeable abutments in internal-connection type implants by Park et al[12] has been used in this study. As the pear-shaped cam rotates, the vertical reciprocal motion of the impact rod applies cyclic loads to the specimen that mimic human chewing cycles. (Fig. 3)[10,11,12] Implants were clamped into an implant holder consisting of a collet and a nut (Nikken, Tokyo, Japan) using a torque wrench (230DB3, Tohnichi, Tokyo, Japan) at a torque of 300 Ncm.[11,12] For vertical loads, this assembly was fixed to the holder along the long axis of the implant. A hemispherical stainless steel metal cap (Wonwi-Chogyung, Seoul, Korea) was applied to the abutments to receive loads conforming to the ISO 14801:2007[12] which modified the direction of the force to the vertical orientation. The metal cap was designed to mimic the presence of a crown and prevent deformation of the abutment from the cyclic loads.[11,12] Tightening torques of 25 Ncm for group 1 and 2 and 30 Ncm for group 3 and 4 were applied to the abutment screw according to the manufacturers' recommendation twice at 10-minute intervals using a digital torque gauge (MGT50, Mark-10, Tokyo, Japan).

(a) (b)



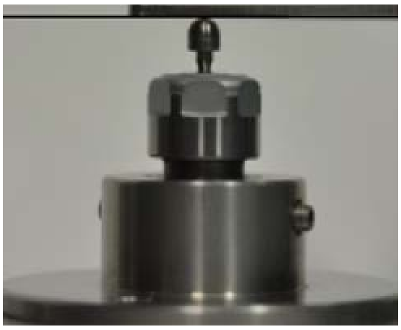


Fig. 3 (a) A cyclic loading device, **(b)** Implant-abutment assembly fixed in implant holder.

Setting the Applied Load

The load cell (MNC-500L, CAS Korea, Seongnam, Korea) was calibrated before each measurement with a strain analysis program (STT-200P, CAS Korea, Seongnam, Korea). Loads of 150 N, which was considered as the physiological occlusal force on the single posterior tooth,[13,14] were applied at a frequency of 3 Hz for 1 million cycles throughout the experiment.[11]

Measuring the Axial displacement of Abutments

The total length of implant-abutment assembly was measured using an electronic digital micrometer (No. 293-240, Mitutoyo, Tokyo, Japan) with an accuracy up to 0.001 mm (1 μm).[11] As a reference point, the length of the implant-abutment assembly after tightening the abutment screw with 5 Ncm was measured. And the length of each assembly was measured after initial tightening with the manufacturer's recommended torque which was 25 Ncm for group 1 and 2, and 30 Ncm for group 3 and 4. After starting to apply the vertical cyclic load, the length of the assembly after each cyclic, 10, 100, 1,000, 10,000, 100,000, 500,000, and 1million, were measured and the change between the cycles were calculated (Fig. 4).

Removal Torque Values Before and After Cyclic loading

After initial tightening with the manufacturers' recommended torque twice at 10-minute intervals, a digital torque gauge was used to measure the abutment screw RTV.[15] Then, after 1 million cyclic loading, the removal torque was measured again in the same way. Because the recommended tightening torques were different for each implant, the reduction rate (%) was also calculated to compare between each group: reduction rate (%) = ((insertion torque – RTV) / insertion torque) X 100.[11]

Tensile Force for Abutment Displacement After Cyclic Loading

The tensile force required to displace the abutments from the implants after 1 million cyclic loading was measured in a universal testing machine (Instron, Norwood, MA, USA). Each abutment had a 1.2 mm diameter hole located 3.5 mm below the top, through which a metal wire was passed to pull it. The abutment-implant assembly was fixed at the bottom part of the machine, and then tensile force was applied at a speed of 0.5 mm/min until the abutment was dislodged.[16]

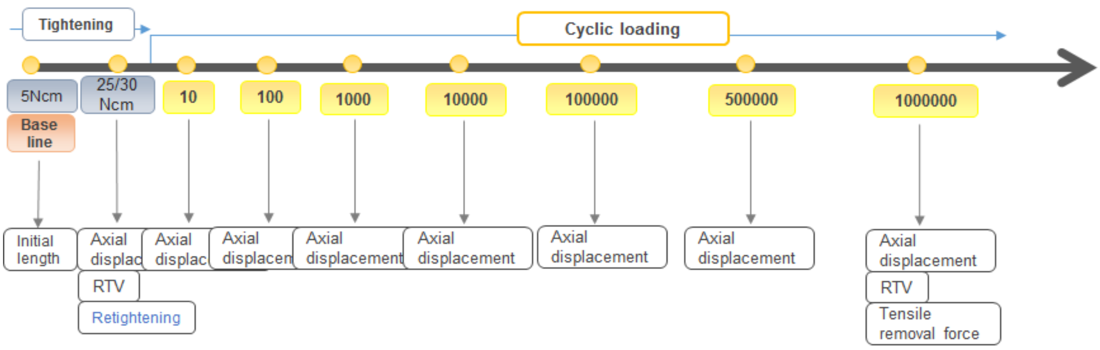


Fig.4 The illustration of each measurement point of the axial displacement value, the RTV and the tensile removal force.

Statistical analysis

A total of 28 abutments, 7 specimens each group, provided multiple repeated measurements during the 10, 100, 1,000, 10,000, 500,000 and 1 million cyclic loading schedules. Since those consecutive measurements were correlated according to the individual specimen, the mixed model analysis was conducted. To evaluate differences among the 4 groups, Tukey's Honestly Significant Difference (HSD) method was applied. The Wilcoxon signed-rank test was conducted to compare before and after values within each group, and the Kruskal-Wallis and Mann-Whitney tests were used to compare the RTV reduction rates before and after cyclic loading and the tensile removal force after cyclic loading between the groups. Pearson correlation analysis was performed to analyze the correlation between the axial displacement value, the RTV reduction rate and the tensile removal torque. Differences at $P \leq .05$ were considered statistically significant. Statistical analyses were performed using the language R (R Development Core Team, Vienna, Austria)[17] and *p*-value of less than 0.05 was considered statistically significant.

III. RESULTS

Axial Displacements After Initial tightening and Cyclic Loading

The length of each assembly measured at 5 Ncm of torque was determined as the baseline,[18] and the axial displacement of the abutment into the implant after initial tightening with 25 or 30 Ncm (manufacturers' recommended torque) was measured. It was - 25.7 ± 7.9 μm in group 1 using prefabricated abutments and - 18.4 ± 13.0 μm in group 2 using CAD/CAM customized compatible abutment manufactured by MyPLANT™. In group 3 and 4 using the CAD/CAM abutment manufactured by the CAD/CAM milling center of the same company with the implants, they were - 28.4 ± 6.3 μm and - 21.7 ± 10.6 μm (Table 2, Fig. 5). The axial displacements of each group were not significantly different.

Table 2 Mean (Standard Deviation) Axial Displacement (in μm) of Implant-Abutment Assemblies After 25 Ncm (for Group 1 and 2) or 30 Ncm (for Group 3 and 4) Tightening

	Group 1	**Group 2**	**Group 3**	**Group 4**
5 Ncm Base line	0 (0)	0 (0)	0 (0)	0 (0)
25 / 30 Ncm Insertion torque	- 25.7 (7.9)	- 18.4 (13.0)	- 28.4 (6.3)	- 21.7 (10.6)

Negative value means the decrease of total lengths of implant-abutment assemblies from the base line.

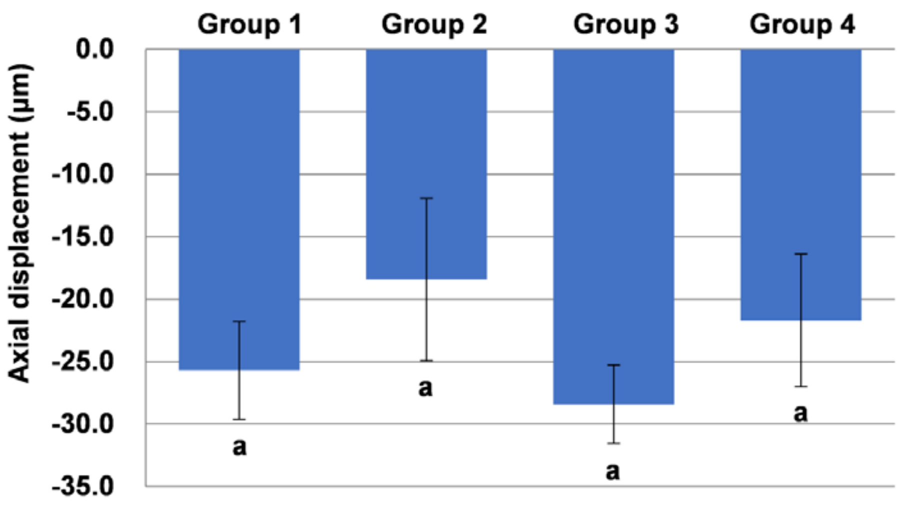


Fig. 5 Axial displacement after 25 Ncm (Group 1 and 2) or 30 Ncm (Group 3 and 4) tightening. Letters indicate groups not statistically significantly different.

The axial displacements of the implant-abutment assemblies after various cyclic loadings are shown in Table 3 and Fig. 6.

Table 3 Mean (Standard Deviation) Axial Displacement (in μm) of the Abutment After Various Cyclic loading. Same letters in same row expressed statistically no significant difference

Cycles	Group 1	Group 2	Group 3	Group 4
0	0 (0)	0 (0)	0 (0)	0 (0)
10	- 4.3 (1.8) [a]	- 4.1 (2.4) [a]	- 5.4 (0.8) [a]	- 4.9 (2.0) [a]
100	- 6.4 (2.2) [b]	- 5.1 (2.7) [b]	- 6.9 (1.5) [b]	- 6.9 (2.7) [b]
1,000	- 7.4 (2.8) [c]	- 7.3 (2.6) [c]	- 7.1 (1.6) [c]	- 8.1 (2.9) [c]
10,000	- 7.9 (3.1) [d]	- 9.4 (4.0) [d]	- 8.0 (1.9) [d]	- 8.9 (3.0) [d]
100,000	- 8.0 (2.9) [e]	- 9.9 (3.9) [e]	- 8.1 (2.1) [e]	- 9.3 (3.0) [e]
500,000	- 8.4 (3.1) [f]	- 10.0 (4.1) [f]	- 8.3 (2.3) [f]	- 9.4 (3.2) [f]
1,000,000	- 9.0 (3.5) [g]	- 10.6 (4.3) [g]	- 8.9 (2.9) [g]	- 9.4 (3.2) [g]

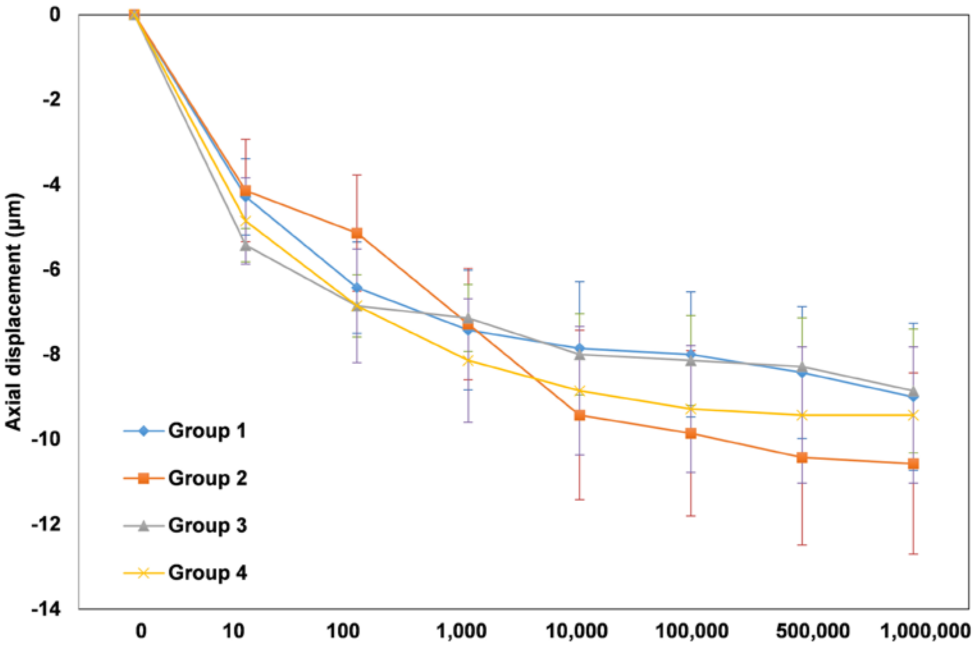


Fig. 6 Axial displacements of the abutments after various cyclic loading.

After 1 million cyclic loading, axial displacement occurred in all groups (- 9.46 ± 3.37 μm) and no significant difference was found between the prefabricated abutment and the CAD/CAM abutment. In control group (Group 1), the value was - 9.0 ± 3.5 μm, and - 10.6 ± 4.3 μm in group 2 with MyPLANT™ fabricated CAD/CAM abutment, and - 8.9 ± 2.9 μm, - 9.4 ± 3.2 μm in group 3 and 4, respectively. Fig. 6 shows that as the number of cycles increased, the axial displacement value did not increase continuously but the rate of axial displacement decreased after about 10^4 cyclic loading. The lengths of the implant-abutment assemblies were measured at exponential time points of cyclic loading (10^n), and log transformation of both the axial displacement values and the number of cycles was performed. For more accurate pattern analysis, linear mixed analysis was performed. In all groups, the linearity on log transformation was observed, every time the log value of the cycle number increased by 1, the logarithmic value of axial displacement increased by 0.05, that is, when the cycle number increased by 10 times, the amount of axial displacement increased by $10^{0.05}$ = 1.12μm. There was no significant difference among the groups ($P \leq .001$). Fig. 7 shows estimated effects of the number of cycles to the axial displacements in logarithmic scale, and the plots were linear.

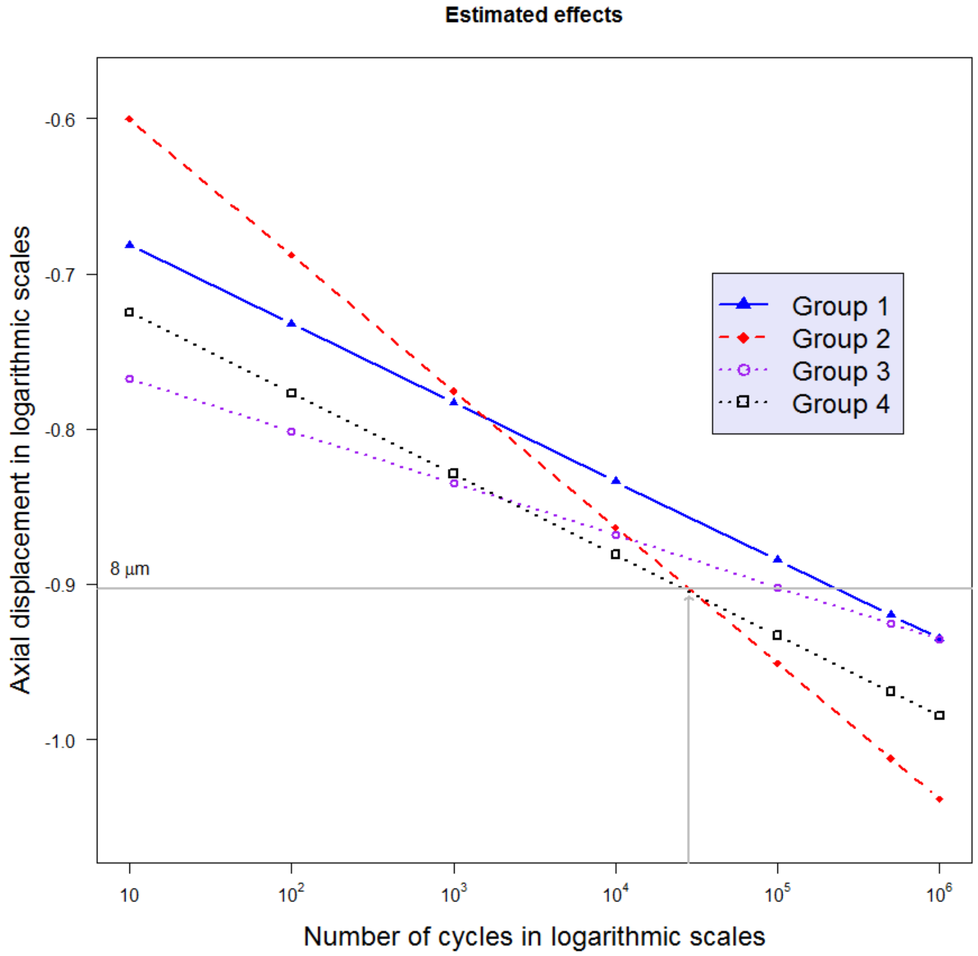


Fig. 7 Estimated effects of the number of cyclic loading to the axial displacement in logarithmic scale. Every time the log value of the cycle number increased by 1, the logarithmic value of axial displacement increased by 0.05. When the number of cycles was $10^{4.45}$, the axial displacement values reached 8 μm.

The final axial displacement values obtained by combining the axial displacement after initial tightening and the value after 1 million cyclic loading are shown in Fig. 8.

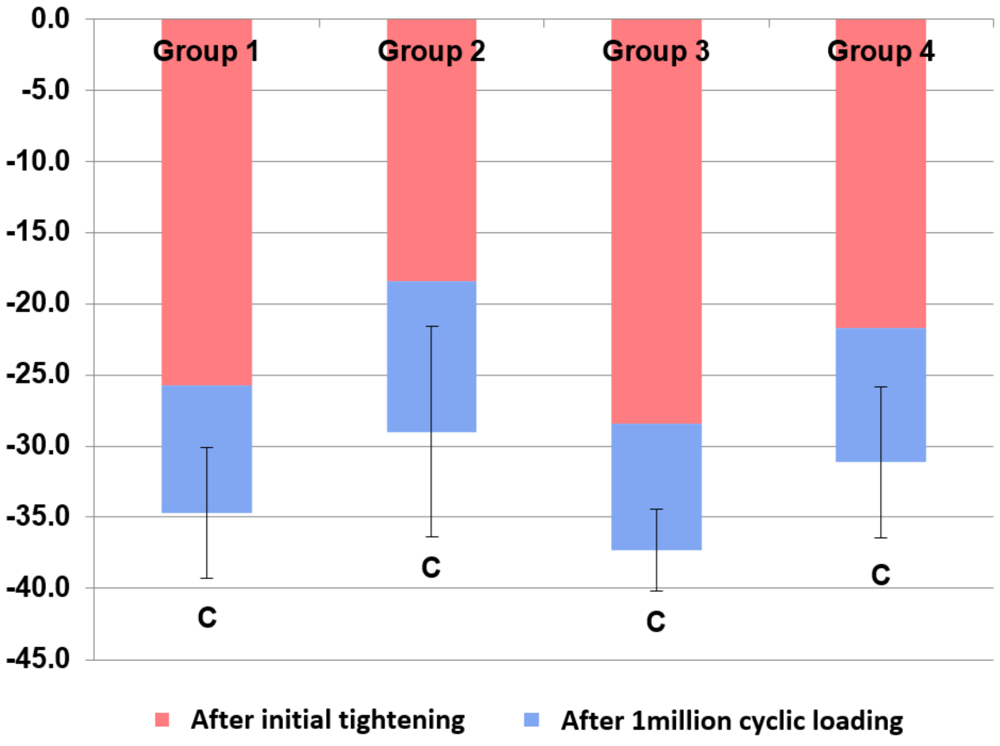


Fig. 8 Total axial displacement after initial tightening and after 1 million cyclic loading (The point of 5 Ncm tightening as the reference point). Red bar: axial displacement after insertion tightening with 25 Ncm for group 1,2 and 30 Ncm for group 3,4 (as manufacturers' recommended). Blue bar: axial displacement during cyclic loading. Letters indicate groups not statistically significantly different.

Removal Torque Values Before and After Cyclic Loading

The RTV reduction rate (RTV values) before cyclic loading was 26.9 ± 5.9 % (18.3 ± 1.5 Ncm) in group 1 using prefabricated abutment and 29.7 ± 6.7% (17.6 ± 1.7 Ncm) in group 2 using CAD/CAM customized compatible abutment manufactured by MyPLANT^{TM}. In group 3 and 4 using the CAD/CAM abutment manufactured by the CAD/CAM milling center of the same company with the implant, they were 21.0 ± 4.3 % (23.7 ± 1.3 Ncm) and 21.4 ± 6.0 % (23.6 ± 1.8 Nm). After cyclic loading, it was 46.9 ± 8.2 % (13.3 ± 2.1 Ncm) in group 1, 60.3 ± 3.4 % (9.9 ± 0.8 Ncm) in group 2, 52.1 ± 5.5 % (14.4 ± 1.6 Ncm) in group 3 and 55.7 ± 8.6 % (13.3 ± 2.6 Ncm) in group 4. The RTVs and the reduction rates of RTV before and after cyclic loading are presented in Table 4 and Fig. 9.

Table 4 Mean (Standard Deviation) RTVs Before and After 1 million Cyclic Loading

	Group 1		**Group 2**		**Group 3**		**Group 4**	
	Before	After	Before	After	Before	After	Before	After
RTV (Ncm)	18.3 (1.5)	13.3 (2.1)	17.6 (1.7)	9.9 (0.8)	23.7 (1.3)	14.4 (1.7)	23.6 (1.8)	13.3 (2.6)
Reduction rate (%)	26.9 (5.9)	46.9[2] (8.2)	29.7[1] (6.7)	60.3[2] (3.4)	21.0[1] (4.3)	52.1 (5.5)	21.4 (6.0)	55.7 (8.6)

The RTVs after cyclic loading were significantly lower than those before cyclic loading in all groups ($P \leq .05$). [1,2]The only statistically significant differences were between the maximum and minimum values measured before and after cyclic loading ($P \leq .05$). RTV = Removal torque values; Reduction rate (%) = (25 – RTV) / 25 for group 1,2 and Reduction rate (%) = (30 – RTV) / 30 for group 3, 4.

(a) (b)

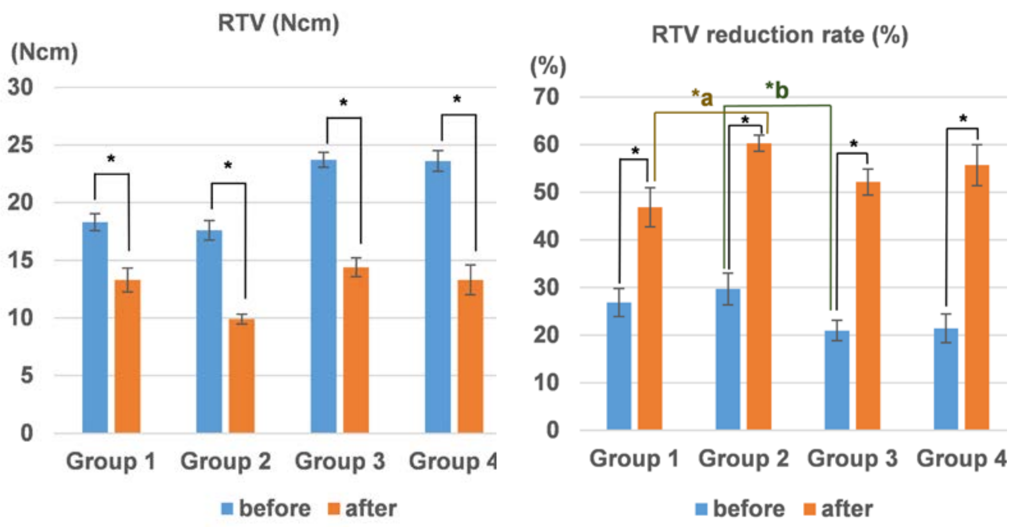


Fig. 9 (a) RTVs before and after 1 million cyclic loading. The RTVs decreased after cyclic loading significantly in all groups ($p < .05$), **(b) RTV reduction rate (%) compared to the initial tightening torque.** RTV = Removal torque values; Reduction rate (%) = (25 – RTV) / 25 for group 1,2 and Reduction rate (%) = (30 – RTV) / 30 for group 3, 4. *: statistically significant differences between the values before and after in a group, *a,*b: statistically significant differences between groups

The Wilcoxon signed-rank test was used to compare before and after values within each group. In all groups, the RTV reduction rates after cyclic loading were significantly lower than those before cyclic loading ($P \leq .05$). The RTV reduction rate before cyclic loading was lowest in group 3 and highest in group 2, whereas after cyclic loading the rate was lowest in group 1 and highest in group 2. The only statistically significant differences were between the maximum and minimum values measured before and after cyclic loading ($P \leq .05$).

Tensile Force Required to Dislodge Abutments from the Implants After Cyclic Loading

After 1 million cyclic loading, the abutment screws were removed measuring RTVs. Even after that, all the abutments were sustained in implants and only after tensile force was applied, they were removed from the implants. The tensile force to remove the abutment from the implant after cyclic loading was 46.8 ± 11.2 N in group 1 using prefabricated abutment and it was 52.9 ± 10.4 N in group 2 using CAD/CAM customized compatible abutment manufactured by MyPLANT™. In group 3 and 4 using the CAD/CAM abutment manufactured by the original company as the implant, they were 47.4 ± 7.7 N and 50.5 ± 6.8 N. The mean (standard deviation) tensile removal forces in each group are shown in Table 5 and Fig. 10. The overall mean tensile removal force was 49.4 ± 9.0 N, and a Kruskal-Wallis test revealed no significant difference between the groups.

Table 5 Mean (Standard Deviation) Tensile removal force (N) After 1 million cyclic loading

	Group 1	**Group 2**	**Group 3**	**Group 4**
Tensile force (N)	46.8 (11.2)	52.9 (10.4)	47.4 (7.7)	50.5 (6.8)
The overall mean tensile removal force was 49.4 ± 9.0 N, and a Kruskal-Wallis test revealed no significant difference between the groups.				

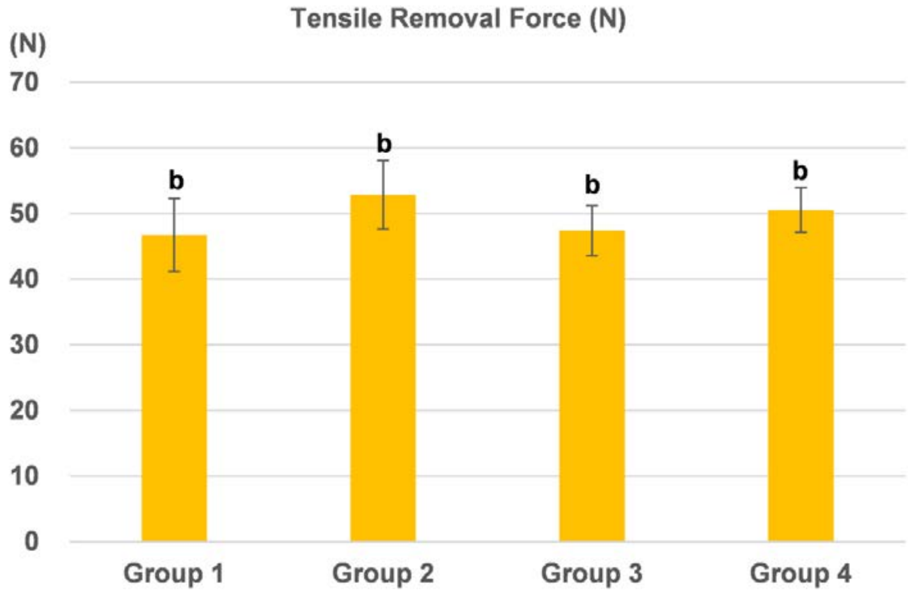


Fig. 10 Tensile force to displace the abutments from the implants after 1 million cyclic loading. Letters indicate groups not statistically significantly different.

Correlation of Axial displacement, RTV reduction rate and Tensile removal force

Based on the above experimental results, it was predicted that a correlation between the axial displacement value, RTV reduction rate and tensile removal force after 1 million cyclic loading would be present (Table 6), and Pearson correlation analysis revealed a significant correlation between these three values at the 0.01 level (Table 7).

Table 6 Values of axial displacement (μm), RTV reduction rate (%) and Tensile removal force (N) after 1 million cyclic loading

	Axial displacement (μm)	RTV reduction rate (%)	Tensile removal force (N)
Group 1	- 9.0 (3.5)	46.9 (8.2)	46.8 (11.2)
Group 2	- 10.6 (4.3)	60.3 (3.4)	52.9 (10.4)
Group 3	- 8.9 (2.9)	52.1 (5.5)	47.4 (7.7)
Group 4	- 9.4 (3.2)	55.7 (8.6)	50.5 (6.8)

Table 7 Pearson correlation efficient among axial displacement (μm), RTV reduction rate (%) and Tensile removal force (N) after 1 million cyclic loading

	Axial displacement[1] (μm)	RTV reduction rate (%)	Tensile removal force (N)
Axial displacement[1] (μm)	1	.506**	.810**
RTV reduction rate (%)	.506**	1	.647**
Tensile removal force (N)	.810**	.647**	1

The value of axial displacement[1] used in this correlation analysis is absolute value of actual axial displacement which for comparison with RTV reduction rate and Tensile removal force. **: The correlation is significant at the 0.01 level.

Linear regression analysis of the relationship between these values showed the strongest linear relationship between the axial displacement and the tensile removal force, also shown by the Pearson correlation analysis (Fig. 11).

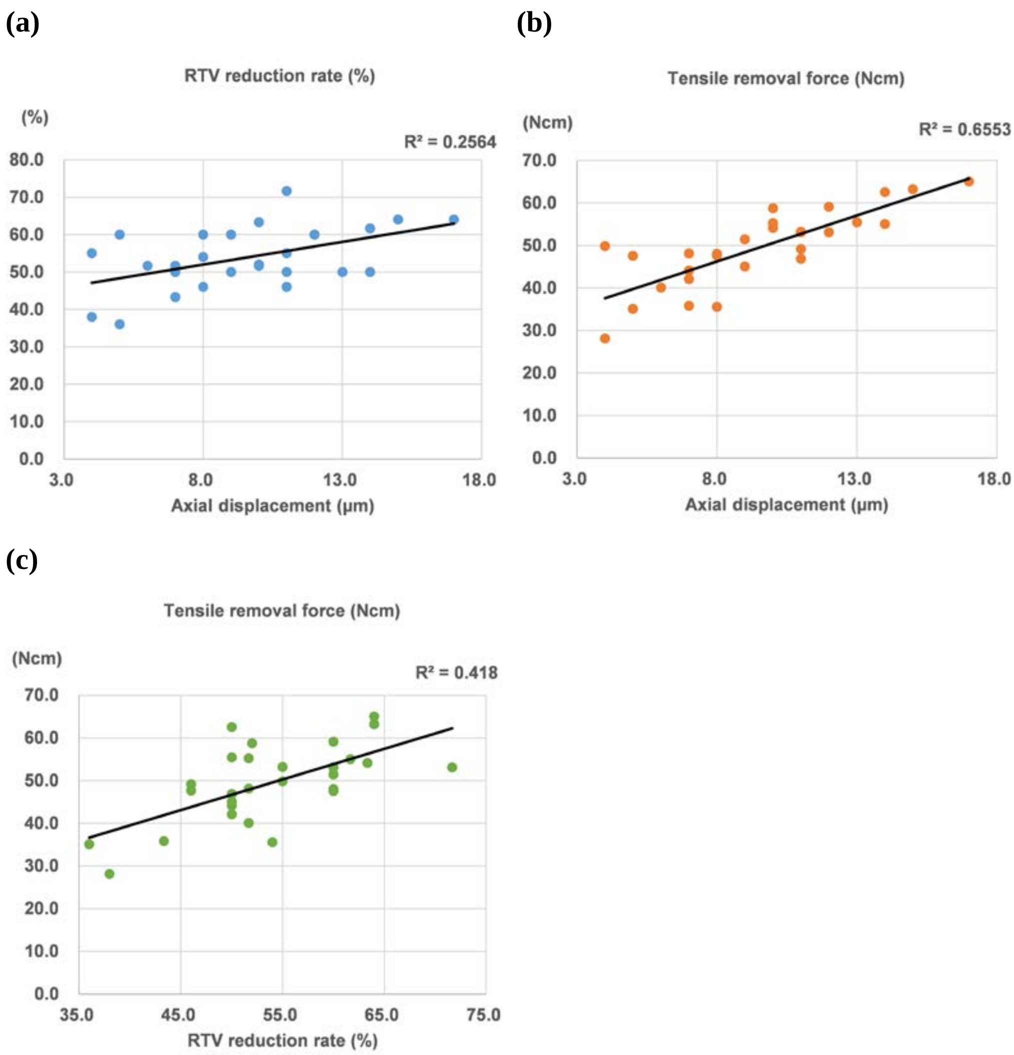


Fig. 11 Linear regression analysis between **(a)** Axial displacement* and RTV reduction rate, (R^2 = 0.26) **(b)** Axial displacement* and Tensile removal force, (R^2 = 0.66) and **(c)** RTV reduction rate and Tensile removal force (R^2 = 0.42) after 1 million cyclic loading. The value of axial displacement* used in this graph is absolute value of actual axial displacement which for comparison with RTV reduction rate and Tensile removal force.

IV. DISCUSSION

Clinicians often encounter situations in which the occlusion of implant prostheses has been weakened a few months after restoration with internal connection type implants. Lee et al compared the axial displacement of implants with external- and internal-type abutments, reported that external-type implants with flat platform interfaces showed the least axial displacement and observed greater axial displacement in the internal tapered implant system.[19] Seol et al also reported greater axial displacement in internal-type implants than external-type implant system, and the amount of axial displacement after 1 million cyclic loading was - 9.0 μm in internal connection type implant–prefabricated abutment assembly.[11] The present study assessed the amount of axial displacement of CAD/CAM abutments into the internal-type implants manufactured by the original manufacturers of the implants and compatible abutments manufactured by the CAD/CAM abutment laboratory. There was no significant difference between prefabricated abutments and CAD/CAM abutments, and the axial displacement after 1 million cyclic loading of the internal-type implant was - 9.46 ± 3.37 μm on average regardless of the abutment type which was comparable to that seen in the previous study.[11.18.19] This value is less than the threshold of tactile sense in natural teeth (20 μm) and implants (50 μm);[20,21] however, it is larger than that of the thickness of the shimstock occlusion test foil (Hanel, Contene/Whaledent, AG, Altstätten, Switzerland) commonly used for occlusal checks (8 μm), and it is a size within a range that could be detected by dentists and by some sensitive patients. The axial displacements measured after insertion tightening with the manufacturers' recommended torque did not significantly differ among the groups. During cyclic loading, it was noticed that the axial displacement value in group 2 using Astra OsseoSpeed™ implants and MyPLANT™ manufactured CAD/CAM abutments, which was the lowest among the groups before 1,000 cyclic loadings, became the highest value after 10,000 cyclic loadings. Ultimately, although a maximum displacement of - 10.6 ± 4.3 μm was measured after 1 million cyclic loading, the change in axial displacement was not significantly different between the groups (Fig. 6). There was a difference from Yilmaz's previous study, which measured the three-dimensional position of the same nine abutments manufactured by different manufacturers that the customized abutment manufactured by the original manufacturer was better than the compatible copy abutment.[22] In the current study, no significant difference was detected between CAD/CAM customized abutments manufactured by the CAD/CAM milling center of the same company with implants and those manufactured by the other CAD/CAM laboratory, however, a higher axial displacement value appeared in group 2. Therefore, when using CAD/CAM customized abutments not manufactured by the original manufacturer, it is required to compensate for the axial displacement.

The axial displacement value did not increase continuously but the rate of axial displacement decreased after about 10,000 cycles. As the number of cycle increased, the amount of axial displacement variation decreased but no plateau pattern was observed, which means it was predicted that the axial displacement will be occurred continuously even after 1 million cycles. When the cycle number increased by 10 times, the amount of axial displacement increased by 1.12μm. Fig. 7 shows when the number of cycles was $10^{4.45}$ = 28,184, the axial displacement value reached 8 μm, the thickness of the shimstock occlusal test foil, which dentists could detect the change in occlusion. In this study, the cyclic loads equivalent to 1 year was assumed 1 million cycles,[23,24] therefore the 30,000 cycles correspond to about 11 days. Therefore, for clinical application, when using CAD/CAM customized abutments, to compensate the axial displacement and the related removal torque reduction, it is recommended to retighten the abutment screw after at least two weeks from the initial insertion of the abutment and the prosthesis delivery for which the rate of axial displacement is minimized. Fabricating a precise abutment with an accurate fixture level impression is not less important either.

Fig. 8 shows the final axial displacement values obtained by combining the axial displacement after initial tightening and the value after 1 million cyclic loading. The CAD/CAM abutments manufactured by MyPLANT™ were identical in appearance to the Astra TiDesign™ abutments, however, they were not apparently allowed to sit enough due to the difference in friction coefficient of the interface contacting the implants. In group 2, the displacement value was the lowest at initial tightening but highest after cyclic loading, indicating that the abutment and the prosthesis were not allowed to sit enough at the time of insertion and that a certain amount of settling would occur after masticatory function started. It also means that an adequate preload was not applied to the abutment screw at the time of initial insertion of abutment with prosthesis delivery; therefore, the abutment screw loosening is likely to occur after the prosthesis is used.

RTV reduction rate was a numerical value that could reliably predict abutment screw loosening. Before cyclic loading, the RTV values decreased in comparison with the tightening torque in all groups, and it could be explained by the phenomenon called sedimentation effect[16,25] which brought about by micro-roughness present on the machined surfaces that impairs the initial contact between the threads of the screw and the implants.[26,27,28] Cerutti-Kopplin et al[29] showed that the reverse torque of indexed conical abutments with retention screws was 15.3 % lower than the insertion torque, and comparable results were observed in present study (24.1 ± 6.6 %), with the highest values of 29.7 ± 6.7 % in group 2 (Table 4, Fig. 9). The RTVs decreased significantly after 1million cyclic loading in all groups. The RTV reduction rate was lowest in group 1 and highest in group 2 after 1 million cyclic loading, with the only statistically significant differences measured between the maximum and the minimum values before and after cyclic loading ($P \leq .05$). Paek et al[30] measured RTV values of CAD/CAM abutments and prefabricated abutments before and after 5,000 cyclic loading in the previous study, and no significant difference was found between them. In this study, RTV values before and after 1 million cyclic loading were measured, a significantly higher RTV reduction rate was observed in CAD/CAM abutments manufactured by MyPLANT™ than in prefabricated abutments. The remarkable aspect was that both the axial displacement value and the RTV reduction rate after 1 million cyclic loading were the largest in group 2, which could be interpreted that after application of the abutment and the implant prosthesis, axial displacement occurs more likely when using CAD/CAM customized abutments manufactured by a different manufacturer from the company of implants. With masticatory function started, the preload applied to the abutment screw decreases, and the removal torque decreases accordingly, thus the possibility of the abutment screw loosening increases.

For all the groups, after 1 million cyclic loading, even after the abutment screws were removed, all the abutments were sustained in implants. However, when the tensile removal force was applied, all the abutments displaced from the implants. The overall mean tensile removal force was 49.4 ± 9.0 N and was not significantly different between the groups (Table 5, Fig. 10). De Oliveira Silva et al reported that 44.97 ± 16.15 N was necessary to remove from the implants for straight abutments with index, which similar to the result of the present study, and greater tensile force, 60.38 ± 19.65 N was required for straight abutments without index.[16] That is, even after the abutment screw has been loosened, the abutment could be fixed to remained in the implant. Like the preceding, the maximum value of tensile removal force was measured in group 2, as were the axial displacement and RTV reduction rate after 1 million cyclic loading. This result means that the mechanical load increased the contact surface between the interface of the implant and abutment, or caused surface deformation thereby increasing friction between them, which enabled stabilization of the abutment within the implant even after the abutment has been screw loosened.

Pearson correlation analysis revealed a significant correlation among the axial displacement value, RTV reduction rate and tensile removal force after 1 million cyclic loading at the 0.01 level (Table 7). Thus, as the axial displacement increases, both the amount of reduction in removal torque and the tensile removal force increase. Linear regression analysis of the relationship between these values showed the strongest linear relationship to be between the axial displacement and the tensile removal force, a finding also shown by the Pearson correlation analysis (Fig. 11).

Increasing the tensile force to remove the abutment from the implant means that the contact between their interfaces is stabilized. However, the tensile removal force value is 49.4 ± 9.0 N on average, which is insufficient to resist the lateral force ranging 181 – 608 N[30] to cause loss of contact stabilization between the interfaces of the abutment and the implant. Based on these results, the abutment screw is responsible for the effective retention and the friction between the interfaces of the components acts in a secondary manner. Considering that the removal torque decreases with increasing axial displacement, it can be concluded that the loss of stability due to the reduction of removal torque is greater than the gain from tensile removal force due to axial displacement.

This study was conducted under the assumption of situation of a single internal connection type implants with a hex-indexed abutment in posterior molar region, therefore the results of the present study may not be generalized to other situation such as splinted, non-indexed abutments. In this regard, additional experiments are recommended to compare indexed to non-indexed abutment or single to splinted implant prosthesis.

V. CONCLUSION

The CAD/CAM customized abutment in internal-connection type implant did not show significant difference from the prefabricated abutment in an axial displacement value and tensile removal force. However, a significantly higher RTV reduction after cyclic loadings was observed in CAD/CAM abutments manufactured by the other company from the implant manufacturer. Even though, as the number of cyclic loading increases, the amount of tensile removal force increases, the stabilizing effect at the interface that can be obtained is not so expectable. The axial displacement after 1 million cyclic loadings to the internal connection type implants averaged - 9.46 ± 3.37 μm, and was - 10.6 ± 4.3 μm in CAD/CAM customized abutment manufactured by the other company with the implant manufacturer. This value is less than the threshold of tactile sense in natural teeth however, it can be detected as a difference in some patients, which means if the internal-connection type abutment and definitive prosthesis were applied at once, it would be difficult to avoid the underocclusion phenomenon due to axial displacement during mastication. Axial displacement did not increase in proportion to the number of cyclic loadings, but occurred mostly in the early stage and decreased after 10^4 cyclic loadings. Also, after about 30,000 cyclic loading, the axial displacement value reached 8 μm, the thickness of the shimstock occlusal test foil, which dentists could detect the change in occlusion. After 1 million cyclic loading, even after the abutment screws were removed, all the abutments were sustained in implants, however, when the tensile removal force was applied, all the abutments displaced from the implants.

REFERENCES

1. Sumi T, Braian M, Shimada A, Shibata N, Takeshita K, Vandeweqhe S, Coelho PG, Wennerberg A, Jimbo R. Characteristics of implant-CAD/CAM abutment connections of two different internal connection systems. J Oral Rehabil 2012;39:391–398.

2. Lee JH, Park JM, Koak JY, Kim SK, Heo SJ. Comparison of customized abutments made from titanium and a machinable precious alloy. Int J Oral Maxillofac Implants 2016;31:92–100.

3. Baldassarri M, Hjerppe J, Romeo D, Fikl S, Thompson VP, Stappert CF. Marginal accuracy of three implant-ceramic abutment configurations. Int J Oral Maxillofac Implants 2012;27:537–543.

4. Lee CJ, Yang SE, Kim SG. Evaluation of reverse torque value of abutment screws on CAD/CAM custom-made implant abutments. J Korean Acad Prosthodont 2012;50:128–134.

5. Lang LA, Sierraalta M, Hoffensperger M, Wang RF. Evaluation of the precision of fit between the Procera custom abutment and various implant systems. Int J Oral Maxillofac Implants 2003;18:652–658.

6. Siamos G, Winkler S, Boberick KG. Relationship between implant preload and screw loosening on implant-supported prostheses. J Oral Implantol 2002;28:67–73.

7. Merz BR, Hunenbart S, Belser UC. Mechanics of the implant-abutment connection: An 8-degree taper compared to a butt joint connection. Int J Oral Maxillofac Implants 2000;15:519–526.

8. Tesmer M, Wallet S, Koutouzis T, Lundgren T. Bacterial colonization of the dental implant fixture-abutment interface: An in vitro study. J Periodontol 2009;80:1991–1997.

9. Tarnow DP, Cho SC, Wallace SS. The effect of inter-implant distance on the height of inter-implant bone crest. J Periodontol 2000;71:546-549.

10. Kim SK, Koak JY, Heo SJ, Taylor TD, Ryoo S, Lee SY. Screw loosening with interchangeable abutments in internally connected implants after cyclic loading. Int J Oral Maxillofac Implants 2012;27:42–47.

11. Seol HW, Heo SJ, Koak JY, Kim SK, Kim SK. Axial displacement of external and internal implant-abutment connection evaluated by linear mixed model analysis. Int J Oral Maxillofac Implants 2015;30:1387–1399.

12. Park JM, Baek CH, Heo SJ, Kim SK, Koak JY, Kim SK, Belser UC. An in vitro evaluation of the loosening of different interchangeable abutments in internal-connection-type implants. Int J Oral Maxillofac Implants 2017;32(2):350–355.

13. Richter EJ. In vivo vertical forces on implants. Int J Oral Maxillofac Implants 1995;10:99–108.

14. Rosentritt M, Behr M, Gebhard R, Handel G. Influence of stress simulation parameters on the fracture strength of all-ceramic fixed-partial dentures. Dent Mater 2006;22:176–182.

15. Arnetzl GV, Payer M, Falkensammer F, Arnetzl G. Effect of double conical abutment screw on implant preload. Clin Oral Implants Res 2016;27:553–537.

16. De Oliveira Silva TS, Mendes Alencar SM, da Silva Valente V, de Moura CDVS. Effect of internal hexagonal index on removal torque and tensile removal force of different Morse taper connection abutments. J Prosthet Dent 2016;117:621–627.

17. R Development Core Team. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2018.

18. Kim KS, Lim YJ, Kim MJ, Kwon HB, Yang JH, Lee JB, et al. Variation in the total lengths of abutment/implant assemblies generated with a function of applied tightening torque in external and internal implant-abutment connection. Clin Oral Implants Res 2011;22:834–839.

19. Lee JH, Kim DG, Park CJ, Cho LR. Axial displacements in external and internal implant-abutment connection. Clin Oral Implants Res 2014;25:e83–e89.

20. Lundqvist S, Haraldson T. Occlusal perception of thickness in patients with bridges on osseointegrated oral implants. Scand J Dent Res 1984;92:88–92.

21. Jacobs R, van Steenberghe D. Role of periodontal ligament receptors in the tactile function of teeth: A review. J Periodontal Res 1994;29:153–167.

22. Yilmaz B, Gilbert AB, Seidt JD, McGlumphy EA, Clelland NL. Displacement of implant abutments following initial and repeated torqueing. Int J Oral Maxillofac Implants 2015;30:1011–1018.

23. Winkler S, Ring K, Ring JD, Boberick KG. Implant screw mechanics and the settling effect: Overview. J Oral Implantol 2003;29:242-245.

24. Wiskott HW, Nicholls JI, Belser UC. Stress fatigue: Basic principles and prosthodontic implications. Int J Prosthodont 1995;8:105-116.

25. Binon P. Evaluation of the effectiveness of a technique to prevent screw loosening. J Prosthet Dent 1998;79:430-432.

26. Jorge JR, Barao VA, Delben JA, Assuncao WG. The role of implant/abutment system on torque maintenance of retention screws and vertical misfit of implant-supported crowns before and after mechanical cycling. Int J Oral Maxillofac Implants 2013;28:415-422.

27. Delben JA, Gomes EA, Barao VA, Assuncao WG. Evaluation of the effect of retightening and mechanical cycling on preload maintenance of retention screws. Int J Oral Maxillofac Implants 2011;26:251-256.

28. Assuncao WG, Barao VA, Delben JA, Gomes EA, Garcia IR Jr. Effect of unilateral misfit on preload of retention screws of implant-supported prostheses submitted to mechanical cycling. J Prosthodont Res 2011;55:12-18.

29. Cerutti-Kopplin D, Rodrigues Neto DJ, do Valle A, Pereira JR. Influence of reverse torque values in abutments with or without internal hexagon indexes. J Prosthet Dent 2014;112:824-827.

30. Paek J, Woo YH, Kim HS, Pae A, Noh K, Lee H, Kwon KR. Comparative analysis of screw loosening with prefabricated abutments and customized CAD/CAM abutments. Implant Dent 2016 Dec;25(6):770-774.

31. Widmalm SE, Ericsson SG. Maximal bite force with centric and eccentric load. J Oral Rehabil. 1982 Sep;9(5):445-450.

– 국문초록 –

내측연결형 임플란트에서 반복하중에 따른 CAD/CAM 지대주의 수직침하현상

서울대학교 대학원 치의과학과 치과보철학 전공

(지도교수 허 성 주)

이 유 승

목 적 : 본 연구의 목적은 내측연결형 임플란트에서 반복하중 후의 CAD/CAM 맞춤 지대주의 수직침하현상을 평가하는 것으로, CAD/CAM 맞춤 지대주와 기성 지대주의 반복하중 후의 수직침하량, 나사 풀림토크(RTV) 감소율, 임플란트 고정체로부터 지대주 제거시 요구되는 장력을 비교하였다.

방 법 : 네 군의 내측연결형 임플란트–지대주 조합 (1 군: Astra OsseoSpeed™ TX4.0S X 11mm 와 동일 제조사의 기성 지대주(ASTRA TECH, Dentsply IH AB, Mölndal, Sweden), 2 군: Astra OsseoSpeed™ TX4.0S X 11mm 와 타 회사에서 제조한 CAD/CAM 지대주(MyPLANT™, Raphabio, Seoul, Korea), 3 군: Osstem TS II R4.0 X 10mm 와 동일 제조사의 CAD/CAM abutments (OSSTEM IMPLANT, Seoul, Korea), 4

군: Dentium Implantium 4.0 X 10mm 와 동일 제조사의 CAD/CAM abutments (DENTIUM IMPLANT, Seoul, Korea)을 사용하였으며, 각 군 마다 7 개의 시편을 준비하였다. 각각의 임플란트-지대주 조합 시편을 고정하여 150N, 3Hz 의 반복하중을 가하였으며, 10 회, 100 회, 1,000 회, 10,000 회, 100,000 회, 500,000 회, 1,000,000 회 반복하중 후의 수직침하량 및 1,000,000 회 반복하중 후의 나사풀림토크(RTV) 감소율, 임플란트 고정체로부터 지대주 제거 시 요구되는 장력을 측정하였다. 반복하중에 의한 임플란트-지대주 조합의 수직침하량의 영향을 분석하기 위해 혼합 모형 분석 (Mixed model analysis)을 수행하였으며, 각 군 간의 비교를 위해 Tukey 의 HSD 검정 (Tukey's Honestly Significant Difference)을 시행하였다. 각 군 간의 반복하중 전 후의 RTV 감소율 비교를 위해 Wilcoxon 검정을 시행하였으며, 반복하중 후 그룹 간 RTV 감소율과 지대주 제거장력을 비교하기 위해 Kruskal-Wallis 와 Mann-Whitney 검정을 시행하였다. 또한 반복하중 후의 수직침하량, RTV 감소율, 지대주 제거 장력간의 관계를 분석하기 위해 Pearson 상관관계분석을 시행하였다.

결 과 : 1,000,000 회 반복하중 후, 모든 군에서 수직침하현상이 관찰되었으며(평균 − 9.46 ± 3.37 μm), 1 군에서는 − 9.0 ± 3.5 μm, 2 군에서는 − 10.6 ± 4.3 μm, 3 군에서는 − 8.9 ± 2.9 μm, 4 군에서는 − 9.4 ± 3.2 μm 였다. 각 군 간의 유의미한 차이는 발견되지 않았다. 모든 군에서 RTV 값은 반복하중 후에 유의미하게 감소하였다 ($P \leq .05$). 반복하중 후의 RTV 감소율은 1 군에서 46.9 ± 8.2 %, 2 군에서 60.3 ±

3.4 %, 3 군에서 52.1 ± 5.5 %, 4 군에서는 55.7 ± 8.6 % 였다. 반복하중 전 RTV 감소율은 3 군에서 가장 낮고 2 군에서 가장 높았으나, 반복하중 후에는 1 군에서 가장 낮고, 2 군에서 가장 높았으며, 통계적으로 유의미한 그룹 간 차이는 최대값과 최소값 사이에서만 나타났다 (P ≤ .05). 반복하중 후 임플란트 고정체로부터 지대주를 제거하기 위한 장력은 1 군에서 46.8 ± 11.2 N, 2 군에서 52.9 N ± 10.4 N, 3 군에서 47.4 ± 7.7 N 그리고 4 군에서 50.5 ± 6.8 N 였으며, 평균 49.4 ± 9.0 N 으로 그룹간 유의미한 차이는 발견되지 않았다. 1,000,000 회 반복하중 후의 수직침하량, RTV 감소율, 임플란트 고정체로부터 지대주를 제거하기 위한 장력 사이의 상관관계 분석 결과 0.01 수준에서 높은 상관관계를 보였다.

결 론 : 수직침하현상은 모든 군에서 관찰되며, RTV 감소율 및 지대주 제거 장력과 유의미한 상관관계가 있었다. 기성지대주와 CAD/CAM 지대주간의 수직침하량의 유의미한 차이는 관찰되지 않았으나 반복하중 후의 RTV 감소율은 외부제조사 제작 CAD/CAM 지대주에서 유의미하게 높은 값을 보였다. 1,000,000 회 반복하중 후, 지대주 나사를 제거한 후에도 모든 지대주는 임플란트에 고정되어 있었으나, 장력을 적용한 후에는 모두 임플란트로부터 분리되었다.

주요어 : 내측연결형 임플란트, CAD/CAM 지대주, 수직침하량, 나사 풀림 토크, 지대주 제거 장력

학 번 : 2015-31249

감사의 글

박사과정을 무사히 마치고 이 논문을 시작하여 마무리하기까지 많은 도움을 주신 여러 스승님과 동료, 가족에게 감사의 말씀을 전합니다.

치과보철과 수련 및 대학원 생활에 있어 따뜻한 충고와 조언으로 진료와 연구에 귀중한 가르침을 주신 허성주 교수님께 깊은 감사를 드립니다. 병원 진료와 업무로 바쁘신 와중에도 본 논문을 위하여 많은 지도 편달을 해 주셨습니다.

국소의치학이라는 학문의 깊이와 열정을 일깨워주시고, 이번 논문 심사에도 열과 성을 다해주신 곽재영 교수님과 김성균 교수님께도 깊은 감사를 드립니다.

바쁘신 와중에도 본 논문 심사를 위하여 꼼꼼히 살펴주신 치과교정과 이신재 교수님과 연세대학교 치과대학의 심준성 교수님께도 감사드립니다.

항상 격려와 조언을 아끼지 않으신 치과보철학교실의 이재봉 명예교수님, 한중석 교수님, 임영준 교수님, 김성훈 교수님, 김명주 교수님, 권호범 교수님, 여인성 교수님, 윤형인 교수님과 치과보철학교실원 여러분께 이 자리를 빌어 감사의 말씀을 전합니다.

치과보철과 수련기간부터 지금까지 항상 동고동락하며 서로를 격려해 준 동기들과 의국 선후배님들에게도 감사의 말씀을 전합니다.

마지막으로, 오늘의 제가 있기까지 많은 사랑과 정성으로 보살펴주시고 지원해주신 부모님께 깊은 감사를 드리며, 제가 하는 모든 일을 응원 해주는 동생 이은승에게도 고마움을 드립니다.

2018년 8월

이 유 승