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Effect of hemispherical dimples at titanium implant abutments for the retention of cemented crowns

Jung-Hoon Choi[1], Seong-Joo Heo[1]*, Jai-Young Koak[1], Seong-Kyun Kim[1], Ji-Man Park[1], Jin-Soo Ahn[2]
[1]Department of Prosthodontics, [2]Department of Dental Biomaterials Science and Dental Research Institute, School of Dentistry, Seoul National University, Seoul, Republic of Korea

ORCID
Jung-Hoon Choi
https://orcid.org/0000-0003-0364-1770
Seong-Joo Heo
https://orcid.org/0000-0003-0699-4141
Jai-Young Koak
https://orcid.org/0000-0002-0190-0778
Seong-Kyun Kim
https://orcid.org/0000-0001-8694-8385
Ji-Man Park
https://orcid.org/0000-0003-0018-1166
Jin-Soo Ahn
https://orcid.org/0000-0001-6978-5342

PURPOSE. The aim of this study was to assess the effect of hemispherical dimple structures on the retention of cobalt–chromium (Co–Cr) crowns cemented to titanium abutments, with different heights and numbers of dimples on the axial walls. **MATERIALS AND METHODS.** 3.0-mm and 6.0-mm abutments (N = 180) and Co-Cr crowns were prepared. The experimental groups were divided into two and four dimple groups. The crowns were cemented by TempBond and PANAVIA F 2.0 cements. The retention forces were measured after thermal treatments. A two-way Analysis of Variance (ANOVA) and post-hoc Tukey HSD test were conducted to analyze change in retention forces by use of dimples between groups, as well as *t* test for the effect of abutment height change (α = .05). **RESULTS.** Results of the two-way ANOVA showed a statistically significant difference in retention force due to the use of dimples, regardless of the types of cements used (P < .001). A significantly higher mean retention forces were observed in the groups with dimples than in the control group, using the post hoc Tukey HSD test (P < .001). Results of *t* test displayed a statistically significant increase in the retention force with 6.0-mm abutments compared with 3.0-mm abutments (P < .001). The groups without dimples revealed adhesive failure of cements, while the groups with dimples showed mixed failure of cements. **CONCLUSION.** Use of hemispherical dimples was effective for increasing retention forces of cemented crowns. [J Adv Prosthodont 2023;15:63-71]

KEYWORDS
Dental implant; Implant prosthesis; Implant abutment; Retentive force

Corresponding author
Seong-Joo Heo
Department of Prosthodontics, Seoul National University Dental Hospital, 101, Daehak-ro, Jongno-gu, Seoul, 03080, Republic of Korea
Tel +82220722661
E-mail 0504heo@hanmail.net

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INTRODUCTION

Dental implants are widely used clinical options for restoring regions of missing dentition.[1-3] For functional and esthetic prosthetic restoration, the placement of implant fixtures in the optimal position is necessary.[4-6] There are two connection types in dental implant prostheses. The screw-retained type directly connects the upper prosthesis to the implant fixture by abutment screws, whereas the cement-retained type connects the abutment with screws and cements the superstructure.[7]

With its superior retrievability due to abutment screw access holes, screw-retained implant prosthesis is more preferred when the interocclusal distance is limited, i.e. as little as 4.0 mm in height.[8,9] Another benefit of a screw-retained implant prosthesis is that there are no residual cements around the implant-supported crowns and abutments. If the margin of the cement-retained prosthesis of dental implants is deeper than 2.0 mm in depth subgingivally, it is extremely difficult to completely remove the excess cement around the abutment.[10] This poses a major risk for maintaining healthy peri-implant tissue, which may develop into peri-implantitis if left unremoved for years.[11]

On the other hand, cement-retained implant prostheses have several advantages compared with screw-retained types. The cement-retained crowns are retrievable with provisional cementation and the excess cement is removed easily.[12,13] Compared to screw-retained types, the cement-retained types require less complex laboratory and clinical procedures.[14] In terms of esthetic aspects, cement-retained prostheses are more favorable for duplicating the anatomical tooth structure, due to the absence of screw access hole.[15] However, when the abutment height is limited due to clinical situations, shorter titanium implant abutments pose greater risk for unintended decementation since they resulted in significantly lower retention forces according to recent studies.[16,17]

With regard to cement-retained implant-supported crowns, previous studies have assessed improvements in the retention of the superstructure crowns to the abutments by different methods. Farzin *et al*.[18] reported that for cast crowns, the force of retention was significantly improved by various types of temporary cements used. Lopes *et al*.[19] subsequently found that self-adhesive resin cement provided enhanced pull-out retentive force compared with provisional cement, such as RelyX Temp NE. In addition to the role of luting agents, Ganbarzadeh *et al*.[20] insisted that the surface modification of the implant abutment may affect the retention between the abutment and the metal alloy crown. Their experiment provided support for a weaker retentive force by sandblasted titanium abutment surface than a roughened surface by a cylindrical diamond bur. In contrast, the sandblasted implant abutments showed higher retention force than smooth-surface milled implant abutments did.[21]

The use of retention grooves was another method that had been suggested to improve the dislodging force of the cemented crowns. Badawi *et al*.[22] showed that forming circumferential grooves on the implant abutments improved force of retention when cemented by provisional cement. Furthermore, Lewinstein *et al*. stated that addition of circumferential grooves on the abutment effectively enhanced retention force of cemented crowns either with zinc phosphate or zinc oxide provisional cements.[23]

Similar studies have been conducted in a tooth abutment to crown environment. Chan *et al*.[24] reported that forming auxiliary grooves inside of the crown and the dentin abutment enhanced the retentive force compared to the control group with no auxiliary groove. Likewise, O'Kray *et al*.[25] proposed that the use of a single circumferential groove inside the crown significantly increased the retentive force when cementing cast metal crowns to the cobalt-chromium (Co-Cr) alloy die. In fact, forming a single groove the internal surface of the crown resulted in significantly greater retention than placing grooves both on the inside of the crown and the die or on the die alone.

Although much research has been completed on abutment structures in terms of reinforcement of the retentive strength when cemented, only a few studies have investigated the creation of a specific shape of retentive modification on the axial wall of dental implant abutments. The purpose of this study is to investigate the effect of change in force of retention of the cemented crowns by forming hemisphere dimples on the axial walls of implant abutments using various heights and cement types. The null hypothesis is that there will be no difference in the mean retentive force with the use of dimples on the titanium abutment wall in cement-retained implant-supported crowns.

MATERIALS AND METHODS

Cylindrical-shaped internal-type abutments with a height of 3.0 or 6.0 mm were designed by an industrial design software (AutoCad, version 24.1; Autodesk Inc., San Francisco, CA, USA) with hemispherical dimples (Fig. 1). The indented dimples were 1.5 mm in diameter and 0.75 mm in depth, positioned 1.0 mm above the gingival margin line of the abutment. The total convergence angle of the tapered axial wall was 6.0 degrees for all abutments with 3.0-mm cuff height. The diameter of the abutment was 5.5 mm with 2.5-mm wide screw access channel. Each abutment was fabricated using Cincom L32 milling machine (Citizen Machinery Co., Nagano-ken, Japan) from grade 5 titanium. No additional surface treatment was applied after the milling process was complete.

Twelve groups (n = 15) were prepared for this experiment, with a total of 180 titanium abutments. Of 180 titanium abutments, six groups were 3.0 mm in height and the other six groups were 6.0 mm in height. To compare the retention forces between different types of cements within groups, two types were selected: (1) provisional zinc oxide-eugenol cement TempBond (Kerr, Salerno, Italy) and (2) self-etching; dual cure resin cement PANAVIA F 2.0 (Kuraray, Fujimoto, Japan). In this study, 3.0 mm height abutment was referred to as "H3" and 6.0 mm as "H6." The type of cement used was labeled as either "T" for TempBond or "P" for PANAVIA F 2.0. The number of dimples placed were written in Arabic numerals following the type of cement used. The arrangement of the twelve groups in this experiment was as follows: H3-T0, H3-T2, H3-T4, H3-P0, H3-P2, H3-P4, H6-T0, H6-T2, H6-T4, H6-P0, H6-P2 and H6-P4.

For the groups with two dimples on the titanium abutments, the dimples were positioned at exactly 180 degrees opposite to each other on the axial wall. The same hemispherical dimple size was designed and applied to the four-dimple groups. The dimples were positioned exactly 90 degrees away from each other on the axial wall for four-dimple groups. The abutment was scanned by a digital E4 scanner (3Shape, Copenhagen, Denmark) to fabricate upper crown.

The scanned STL file was imported into the Exocad (GmbH, Darmstadt, Germany) software system to design the upper crown. The internal cementation gap was set for 50 µm. The crown was designed

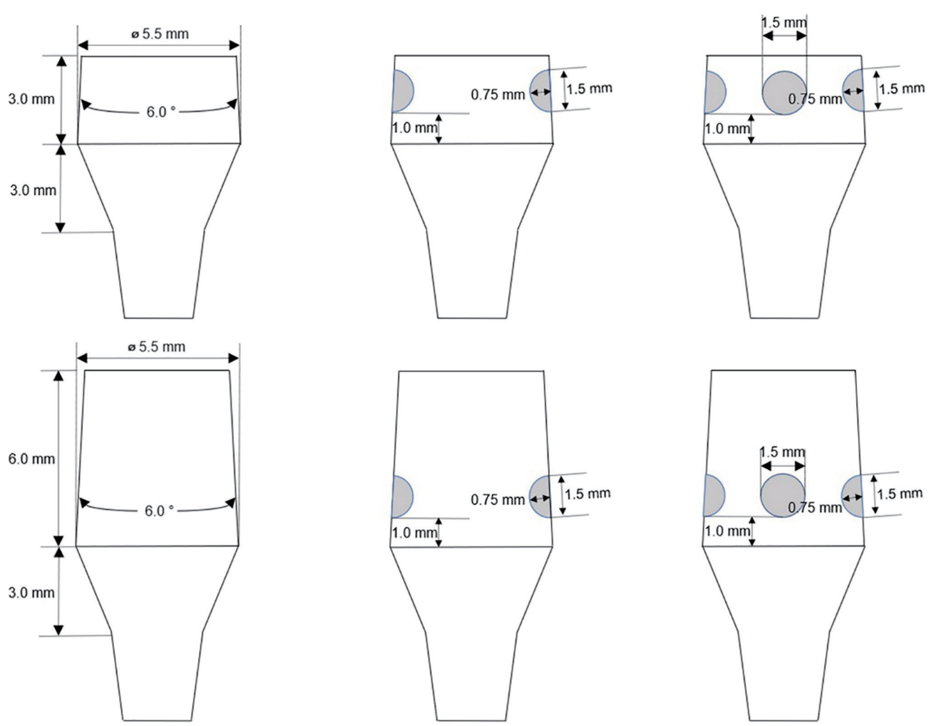

Fig. 1. Dimension of 3.0-mm and 6.0-mm titanium abutments. From left to right: abutment with no dimple, two dimples, and four dimples.

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with a penetrated hole structure (inner diameter: 5.0 mm) directly above the occlusal table to be pulled away from the cemented abutment (Fig. 2). The cobalt-chromium (Co-Cr) crowns were laser sintered by additive manufacturing system EOSINT M270 machine (EOS GmbH Electro Optical Systems, Krailling, Germany). The Co-Cr crowns were then conventionally polished and the intaglio surface of the crown was sandblasted with 50 µm Al_2O_3 under 4.0 bar. The finished Co-Cr alloy crowns are shown in Figure 2.

Commercially available laboratory analogs (Implant; IT system, Warentec, Seoul, Korea) and titanium abutment screws from the same manufacturer were used in this experiment. Each laboratory analog was embedded and fixed into an acrylic resin block. The abutment screws were tightened to the laboratory analogs for 30 N·cm, according to the manufacturer's directions.

The laser sintered Co-Cr alloy crowns were cemented by either TempBond or PANAVIA F 2.0 onto the titanium abutments. Each type of cement was mixed following the manufacturer's instructions. The crowns were then pressed by a load of 5 kg for 10 minute by compression test mode of the universal testing machine (TW-D102; Tae-Won Tech Co., Seoul, Korea). The excess cements were then carefully removed by a dental explorer.

The cemented specimens were placed under a thermocycling environment, where they were submerged into cycles of a cold (5°C) and hot bath (55°C) for 30 seconds each with 5 seconds of dwell time. The tested specimens underwent a total of 10,000 cycles of thermocycling before the retentive force was measured. The pulling hook of the universal testing machine was connected to the cemented crowns (Fig. 3). A uniaxial pull-out load of 5.0 mm/min was applied. The retentive forces needed to dislodge the crowns from the abutments were recorded in Newtons.

The collected data were transferred to the SPSS software version 25.0 (IBM SPSS Inc., Chicago, IL, USA). Once the normality was tested, a parametric two-way Analysis of Variance was conducted to compare the mean retention force according to the change in heights and number of dimples of the titanium abutments as well as their possible interaction effect. The post-hoc Tukey HSD test was also performed to determine the statistical significance within groups for multiple comparisons (α = .05). The effect of abutment height change was analyzed by *t* test and the significance level was set for .05 in all the tests conducted.

RESULTS

The recorded mean retentive forces and standard deviation values for 12 groups are reported in Table 1. The normality test proved that data from all groups followed a normal distribution of retentive forces measured. The results of the parametric two-way ANOVA are presented in Figure 4. Any values lower

Fig. 2. Laser sintered Co-Cr alloy crowns for 3.0-mm and 6.0-mm abutments.

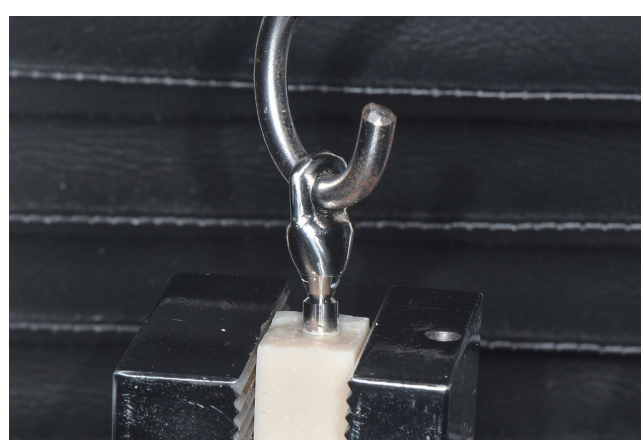

Fig. 3. Universal testing machine (TW-D102; Tae-Won Tech Co., Seoul, Korea) connected to the crown prepared for pull-out test.

Table 1. Mean force of retention with standard deviation for all groups (Newton)

Number of Dimples \ Type of Cement	3.0-mm Ti-abutment		6.0-mm Ti-abutment	
	TempBond	PANAVIA F 2.0	TempBond	PANAVIA F 2.0
0	H3-T0: 81.49 ± 10.12	H3-P0: 279.43 ± 56.00	H6-T0: 133.51 ± 33.73	H6-P0: 432.15 ± 91.39
2	H3-T2: 91.14 ± 14.09	H3-P2: 351.17 ± 85.88	H6-T2: 204.01 ± 44.56	H6-P2: 574.65 ± 71.52
4	H3-T4: 96.05 ± 13.56	H3-P4: 402.49 ± 70.31	H6-T4: 221.01 ± 44.04	H6-P4: 649.62 ± 100.76

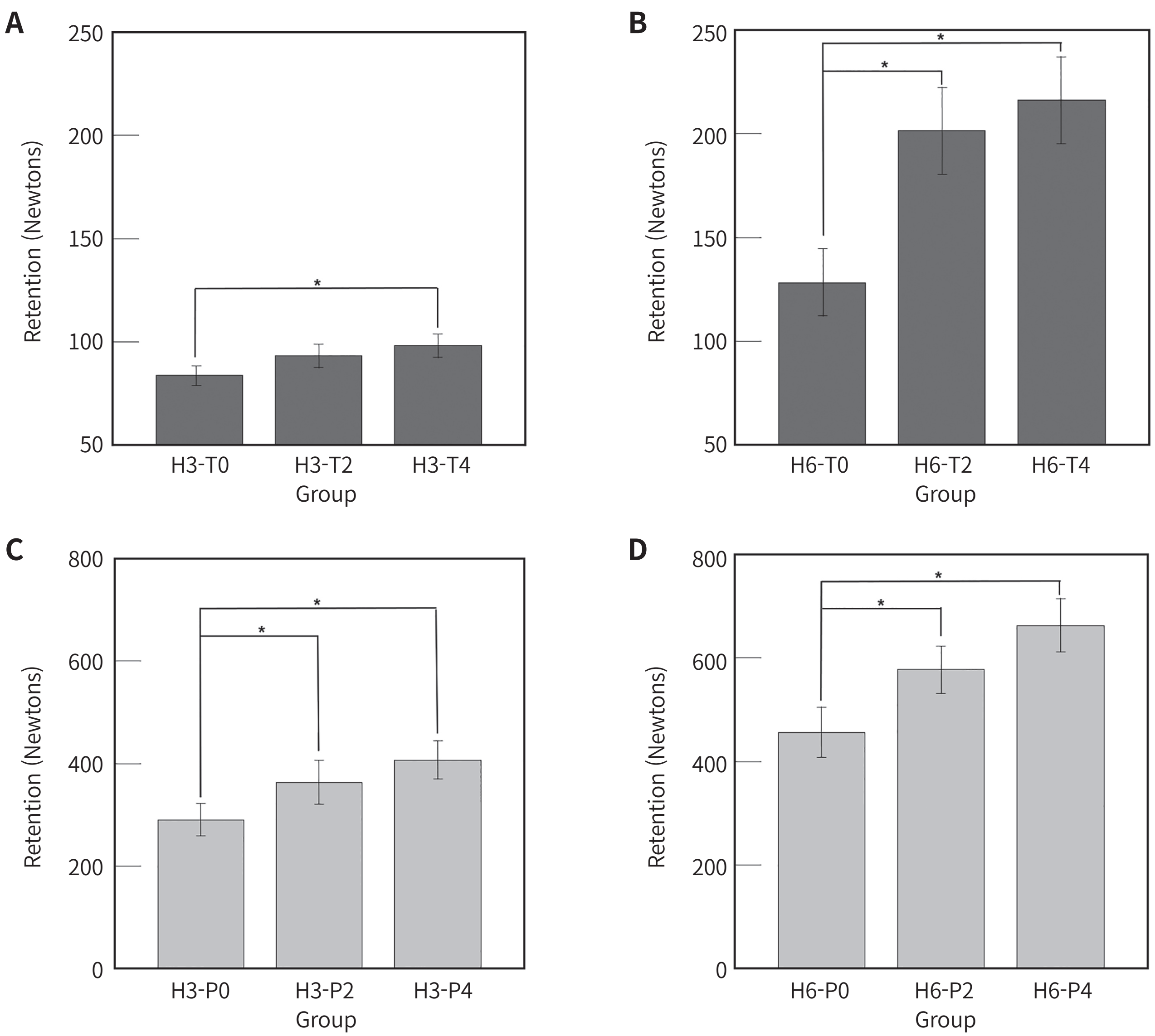

Fig. 4. Summary of two-way ANOVA and post-hoc Tukey HSD for all groups (*$P < .05$). (A) TempBond cementation with 3.0 mm abutments. (B) TempBond cementation with 6.0 mm abutments. (C) PANAVIA F 2.0 cementation with 3.0 mm abutments. (D) PANAVIA F 2.0 cementation with 6.0 mm abutments.
* The mean difference is significant at the .05 level.

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than the proposed significance level (*P* =.05) were considered statistically significant. Bar graph for the collected data with significance is presented in Figure 4.

As the effect of dimples was proved to enhance the retentive forces, post-hoc Tukey HSD test was conducted to investigate the changes within groups. Within the TempBond groups, the H3-T0 group showed no statistically significant difference from the H3-T2 group (*P* > .05), but the H3-T4 group had a significantly higher retention than the H3-T0 group (*P* < .05) and no statistical difference was found between the H3-T2 and H3-T4 groups (*P* > .05). For the 6.0-mm abutments with TempBond cement, both H6-T2 and H6-T4 groups had a statistically significant improvement in retention compared with the H6-T0 group (*P* < .001). However, no significant difference was seen between the H6-T4 and H6-T2 groups (*P* > .05; Fig. 4).

Among the 3.0-mm abutment groups with PANAVIA F 2.0 cementation, the H3-P2 and H3-P4 groups had a statistically enhanced retentive force compared with the H3-P0 group (*P* < .05; Fig. 4), although they were not statistically different from each other (*P* > .05). When the 6.0-mm abutments were tested, the H6-P2 and H6-P4 groups showed a statistically higher mean retentive force than the H6-P0 group (*P* < .001). On the other hand, the H6-P2 and H6-P4 groups were not significantly different from each other (*P* > .05).

The effect of abutment height difference was evaluated by the *t* test. The results of the *t* test showed significantly higher retention forces with 6.0-mm abutments for the TempBond groups compared to 3.0-mm abutments, regardless of the number of dimples used (*P* < .001; Table 2). Similarly, all groups cemented by PANAVIA F 2.0 showed statistically significant changes in the retention force as the abutment height extended from 3.0 to 6.0 mm when the same number of dimples used (*P* < .001; Table 2).

After the pull-out test, remnants of the TempBond cements and PANAVIA F 2.0 cements were mostly left attached to the intaglio surface of the Co-Cr alloy crowns, indicating 100% adhesive failure for the control groups (Fig. 5A and 6A). In all abutments with

Table 2. Summary of *t* test with abutment height change for TempBond and PANAVIA F 2.0 groups

Cement	Dimple \ Height	3.0 mm	6.0 mm	t	*P*-value
TempBond	0	81.49 (10.12)	133.51 (33.73)	-5.772	< .001
	2	91.14 (14.09)	204.01 (44.56)	-10.182	< .001
	4	96.05 (13.56)	221.01 (44.04)	-10.502	< .001
PANAVIA F 2.0	0	279.43 (56.00)	432.15 (91.39)	-5.519	< .001
	2	351.17 (85.88)	574.65 (71.52)	-7.744	< .001
	4	402.49 (70.31)	649.62 (100.76)	-7.790	< .001

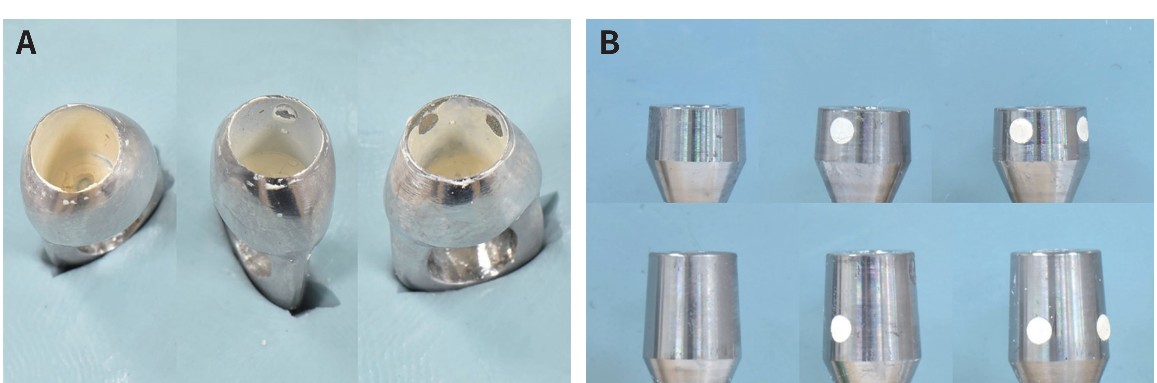

Fig. 5. Cement failure modes for TempBond groups. (A) Intaglio surface of the dislodged Co-Cr crowns. (B) 3.0-mm and 6.0-mm abutments after dislodgement. From left to right: abutment with no dimple, two dimples, and four dimples.

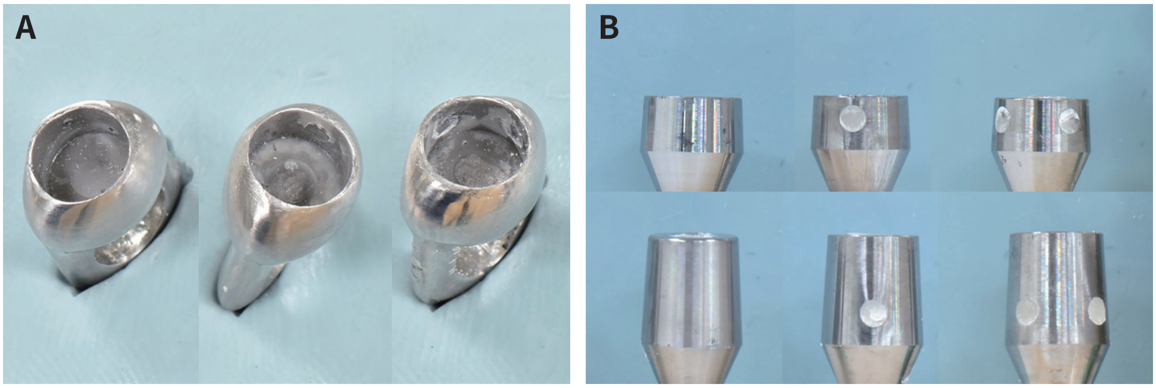

Fig. 6. Cement failure modes for PANAVIA F 2.0 groups. (A) Intaglio surface of the dislodged Co-Cr crowns. (B) 3.0-mm and 6.0-mm abutments after dislodgement. From left to right: abutment with no dimple, two dimples, and four dimples.

dimples, mixed failure modes of both adhesive and cohesive failure were visible. Partial thickness of the cement was left inside the Co-Cr alloy crowns, and the rest was filled inside the dimples, denoting a mixed failure (Fig. 5B and 6B). Groups with dimples showed over 90 % mixed failure of cements.

DISCUSSION

With the satisfaction of normality distribution, two-way ANOVA proved that the abutment height and number of dimples resulted in a statistically significant difference in the mean retentive force for cemented Co-Cr alloy crowns (Fig. 4). This was observed for the specimens cemented by both TempBond groups and PANAVIA F 2.0 groups. Therefore, the null hypothesis of this research that the use of dimple shapes on the titanium abutment would not affect the mean retentive force was rejected.

The crown fabrication method chosen for this study was Co-Cr laser sintering. Since creating the penetrated hole structure with the crown would be a complicated process by milling procedure, laser sintering method was chosen for the crown production method. In addition, previous research also found that milling procedure resulted in significantly lower yield strength and flexural strength than Selective Laser Melting (SLM) procedure.[26] Due to the strong bonding characteristic of PANAVIA F 2.0 cement, laser sintering procedure was suitable for its strength and rigidity of the connection to avoid any unnecessary fractures between the penetrated hole structures and crowns.

Previous research had also shown that with longer abutments, there was a likelihood of greater force of retention when the other conditions were the same.[27,28] This was also supported by this study that when the abutment height changed from 3.0 mm to 6.0 mm, the increase in the mean retention force was significantly greater for 6.0-mm abutments than 3.0-mm abutments.

The second factor of the implant abutment was the surface treatment effect. Ajay *et al*.[29] reported that modifying the surface condition of the implant abutment, such as by sandblasting and bur modification, improved the cement-retained copings. Likewise, Kim *et al*.[30] showed that applying airborne-particle abrasion on the surface of the implant abutment was an effective way of improving retention of cemented crowns. As this research tested only machined-surface titanium abutments, additional surface treatments may have affected the study results.

Another aspect that must be considered is simulating a natural intraoral environment for this *in vitro* study. In a natural environment, implant-supported crowns experience as much force as natural dentition during the mastication process. Studies have shown that compressive cycling loading significantly reduces the dislodging force after cementation is complete.[31,32] However, this study proceeded only for thermal cycling between cold and hot baths after cementation, and the role of cycling loading to the cemented crowns could not be evaluated. Furthermore, if a compressive cyclic loading test was to be performed for this research, the rounded or curved

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upper part of the crown could have been an obstacle to receive an evenly distributed compressive force. Further research on the effect of changing the mean force of dislodgement along with thermocycling simulation is needed.

Although this research could not cover complex factors of surface treatment on the abutment wall and cyclic loading of compression after the cementation process, the purpose of this study was served efficiently with the use of dimple shapes on the mean retentive force impact. The increase in mean retention force by placing hemispherical dimples was statistically significantly different from a plain abutment without dimples for the cemented crowns. Based on this study conducted, long implant abutments (6.0 mm) provide higher retentive forces than short implant abutments (3.0 mm) by both TempBond and PANAVIA F 2.0 cementation. When implant abutment is 3.0 mm in height, it is necessary to use four dimples on the abutment wall, instead of two dimples, to significantly improve the retentive forces compared to a plain abutment without dimples by TempBond cementation. With self-etching and dual cure resin cement such as PANAVIA F 2.0, use of two and four dimples both significantly increase the retentive forces.

CONCLUSION

Within the limitations of this *in vitro* study, the following conclusions can be stated:

TempBond-cemented crowns to 3.0-mm abutments with four dimples showed significantly higher retentive force compared to abutments with no dimple. Two dimples on 3.0-mm abutments showed no significant difference compared to abutments with no dimple by TempBond cementation.

PANAVIA F 2.0-cemented crowns to 6.0-mm abutments with two and four dimples showed significantly higher retentive force compared to abutments with no dimple. Two and four dimples on 6.0-mm abutments showed no significant difference between each other by PANAVIA F 2.0 cementation.

Placing hemispherical dimples on titanium implant abutments could enhance retention forces of cemented Co-Cr crowns especially when the abutment height is as short as 3.0 mm.

REFERENCES

1. Duong HY, Roccuzzo A, Stähli A, Salvi GE, Lang NP, Sculean A. Oral health-related quality of life of patients rehabilitated with fixed and removable implant-supported dental prostheses. Periodontol 2000 2022;88:201-37.
2. Ali Z, Baker SR, Shahrbaf S, Martin N, Vettore MV. Oral health-related quality of life after prosthodontic treatment for patients with partial edentulism: A systematic review and meta-analysis. J Prosthet Dent 2019; 121:59-68.e3.
3. Kurosaki Y, Kimura-Ono A, Mino T, Arakawa H, Koyama E, Nakagawa S, Nguyen HTT, Osaka S, Saeki M, Minakuchi H, Ono M, Maekawa K, Kuboki T. Six-year follow-up assessment of prosthesis survival and oral health-related quality of life in individuals with partial edentulism treated with three types of prosthodontic rehabilitation. J Prosthodont Res 2021;65:332-9.
4. Schmitt A, Zarb GA. The longitudinal clinical effectiveness of osseointegrated dental implants for single-tooth replacement. Int J Prosthodont 1993;6:197-202.
5. Adell R, Lekholm U, Rockler B, Brånemark PI. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. Int J Oral Surg 1981; 10:387-416.
6. Haas R, Mensdorff-Pouilly N, Mailath G, Watzek G. Brånemark single tooth implants: a preliminary report of 76 implants. J Prosthet Dent 1995;73:274-9.
7. Hamed MT, Abdullah Mously H, Khalid Alamoudi S, Hossam Hashem AB, Hussein Naguib G. A systematic review of screw versus cement-retained fixed implant supported reconstructions. Clin Cosmet Investig Dent 2020;12:9-16.
8. Sailer I, Mühlemann S, Zwahlen M, Hämmerle CH, Schneider D. Cemented and screw-retained implant reconstructions: a systematic review of the survival and complication rates. Clin Oral Implants Res 2012; 23:163-201.
9. Chee W, Jivraj S. Screw versus cemented implant supported restorations. Br Dent J 2006;201:501-7.
10. Linkevicius T, Vindasiute E, Puisys A, Peciuliene V. The influence of margin location on the amount of undetected cement excess after delivery of cement-retained implant restorations. Clin Oral Implants Res 2011;22:1379-84.

11. Pauletto N, Lahiffe BJ, Walton JN. Complications associated with excess cement around crowns on osseointegrated implants: a clinical report. Int J Oral Maxillofac Implants 1999;14:865-8.
12. Nematollahi F, Beyabanaki E, Alikhasi M. Cement Selection for cement-retained implant-supported prostheses: a literature review. J Prosthodont 2016;25:599-606.
13. Ma S, Fenton A. Screw- versus cement-retained implant prostheses: a systematic review of prosthodontic maintenance and complications. Int J Prosthodont 2015;28:127-45.
14. Manawar A, Dhanasekar B, Aparna I, Naim H. Factors influencing success of cement versus screw-retained implant restorations: a clinical review. J Osseointegration 2012;4:43-7.
15. Hebel KS, Gajjar RC. Cement-retained versus screw-retained implant restorations: achieving optimal occlusion and esthetics in implant dentistry. J Prosthet Dent 1997;77:28-35.
16. Abbo B, Razzoog ME, Vivas J, Sierraalta M. Resistance to dislodgement of zirconia copings cemented onto titanium abutments of different heights. J Prosthet Dent 2008;99:25-9.
17. Müller L, Rauch A, Reissmann DR, Schierz O. Impact of cement type and abutment height on pull-off force of zirconia reinforced lithium silicate crowns on titanium implant stock abutments: an in vitro study. BMC Oral Health 2021;21:592.
18. Farzin M, Torabi K, Ahangari AH, Derafshi R. Effect of abutment modification and cement type on retention of cement-retained implant supported crowns. J Dent (Tehran) 2014;11:256-62.
19. Lopes ACO, Machado CM, Bonjardim LR, Bergamo ETP, Ramalho IS, Witek L, Coelho PG, Bonfante EA. The effect of CAD/CAM crown material and cement type on retention to implant abutments. J Prosthodont 2019;28:e552-6.
20. Ganbarzadeh J, Nakhaei MR, Shiezadeh F, Abrisham SM. The effect of abutment surface roughness on the retention of implant-supported crowns cemented with provisional luting cement. J Dent Mater Tech 2012;1:6-10.
21. Sahu N, Lakshmi N, Azhagarasan NS, Agnihotri Y, Rajan M, Hariharan R. Comparison of the effect of implant abutment surface modifications on retention of implant-supported restoration with a polymer based cement. J Clin Diagn Res 2014;8:239-42.
22. Badawi H, Aboushady Y, Azer A. Effect of circumferential and axial grooves on the retention of provisionally cement-retained implant-supported crowns (in vitro study). Alex Dent J 2015;40:208-18.
23. Lewinstein I, Block L, Lehr Z, Ormianer Z, Matalon S. An in vitro assessment of circumferential grooves on the retention of cement-retained implant-supported crowns. J Prosthet Dent 2011;106:367-72.
24. Chan KC, Hormati AA, Boyer DB. Auxiliary retention for complete crowns provided by cement keys. J Prosthet Dent 1981;45:152-5.
25. O'Kray H, Marshall TS, Braun TM. Supplementing retention through crown/preparation modification: an in vitro study. J Prosthet Dent 2012;107:186-90.
26. Hong JK, Kim SK, Heo SJ, Koak JY. Mechanical properties and metal-ceramic bond strength of Co-Cr alloy manufactured by selective laser melting. Materials (Basel) 2020;13:5745.
27. Kirman EA, Asar NV, Erdem B, Turkyilmaz I. Effects of abutment length and platform size on the retention of implant-supported CAD/CAM crowns using six different cements. J Dent Sci 2022;17:601-3.
28. Abou-Obaid A, Al-Khudairy R. Effect of abutment height and cement thickness on the retention of cement-retained implant- supported restorations. Adv Dent & Oral Health 2018;9:555767.
29. Ajay R, Suma K, Ali SA, Kumar Sivakumar JS, Rakshagan V, Devaki V, Divya K. Effect of surface modifications on the retention of cement-retained implant crowns under fatigue loads: an in vitro study. J Pharm Bioallied Sci 2017;9:S154-60.
30. Kim Y, Yamashita J, Shotwell JL, Chong KH, Wang HL. The comparison of provisional luting agents and abutment surface roughness on the retention of provisional implant-supported crowns. J Prosthet Dent 2006;95:450-5.
31. Ongthiemsak C, Mekayarajjananonth T, Winkler S, Boberick KG. The effect of compressive cyclic loading on retention of a temporary cement used with implants. J Oral Implantol 2005;31:115-20.
32. Alvarez-Arenal A, Gonzalez-Gonzalez I, deLlanos-Lanchares H, Brizuela-Velasco A, Pinés-Hueso J, Ellakuria-Echebarria J. Retention strength after compressive cyclic loading of five luting agents used in implant-supported prostheses. Biomed Res Int 2016; 2016:2107027.