THE JOURNAL OF PROSTHETIC DENTISTRY

RESEARCH AND EDUCATION

Comparative in vitro study of cementing techniques for implant-supported restorations

Tian Liang, BDS,[a] Xingxue Hu, DMD, PhD,[b] Lin Zhu, BDS,[a] Xueliang Pan, PhD,[c] Yongsheng Zhou, DDS, PhD,[d] and Jianzhang Liu, DDS, PhD[e]

ABSTRACT

Statement of problem. Various techniques are used to cement implant-supported restorations. Excess residual cement is a concern.

Purpose. The purpose of this in vitro study was to evaluate 3 techniques for cementing implant-supported restorations.

Material and methods. Twelve crowns and implant-abutment complexes (IAC) were cemented with 3 techniques: technique 1, a certain amount of cement evenly placed and excess cement removed with an explorer; technique 2, a smaller amount of cement without removal of excess cement; technique 3, a resin abutment replica used for excess cement removal after using a large amount of cement. Each specimen was treated with each technique 3 times. Precementing discrepancies (predis) and postcementing discrepancies (postdis) between IACs and crowns and the postcementing linear roughness (Ra and Rz) on designated junction areas of each specimen were measured. Tensile strength of the specimens was recorded with a universal testing machine at a crosshead speed of 0.5 mm/min. Repeated measures analysis with mixed models was used for differences among the 3 cementing techniques (α=.05).

Results. Compared with techniques 1 and 2, the specimens with technique 3 showed significantly lower mean differences between postdis and predis and Ra and Rz and higher mean tensile strength (P<.05).

Conclusions. The application of a resin abutment replica for the cementation of implant-supported restorations decreased the discrepancy between the restoration and abutment, reduced cement residue, and increased restoration retention. (J Prosthet Dent 2016;116:59-66)

Cement- or screw-retained implant restorations have been widely used in dental clinical practice. The advantages of the cement-retained pattern include ease of use, a passive fit, good esthetics, and resistance to porcelain fracture.[1-3] However, excess cement at the junction of the bonded surfaces that could lead to periimplantitis is a disadvantage of this technique.[4-8] Thorough removal of the excess cement is generally a challenge, particularly with subgingival margins.[5,7,9] Residual cement may lead to a marginal discrepancy and increase surface roughness at the junction between the restoration and implant-abutment complex (IAC).[5] Surface roughness, together with the vulnerable connective tissues, decreases vascularity around the implants and harbors subgingival bacteria that then damage the periimplant tissue and cause the vertical destruction of the crestal bone and implant failure.[5,10,11] Interim cement may be preferred because of easier retrievability of the restoration and excess cement removal despite low retention and high solubility,[12,13] With a decrease in the necessity for retrievability and an increase in the demand for stronger retention, definite types of cement have also been widely used.[14,15] However, the complete removal of resin cement is

Supported by the National Key Clinical Specialty Construction Project of China (2011).
[a]Student, Department of Prosthodontics, Peking University School and Hospital of Stomatology, Beijing, China.
[b]Research Scientist and General Practitioner, The Forsyth Institute, Cambridge, Mass; and Adjunct Assistant Professor, Division of General Practice and Materials Science, The Ohio State University College of Dentistry, Columbus, Ohio.
[c]Research Scientist, Center for Biostatistics, The Ohio State University College of Medicine, Columbus, Ohio.
[d]Professor, Department of Prosthodontics, Peking University School and Hospital of Stomatology, Beijing, China.
[e]Associate Professor, Department of Prosthodontics, Peking University School and Hospital of Stomatology, Beijing, China.

Clinical Implications

Application of a resin abutment replica for the cementation of implant-supported restorations is recommended to minimize cement residues, facilitate passive fit, and reduce occurrence of periimplantitis.

challenging, and scratches from the removal of excess cement with sharp instruments could increase the surface roughness of restoration surfaces.[16,17]

Cementing techniques with the following features are considered favorable: minimal residual cement to achieve a passive fit with no cement flowing out of the border between the crown and abutment; minimal roughness at the restoration-IAC junction to alleviate bacterial accumulation; and optimal retention for the restoration. Several techniques have been proposed. One of these techniques is known as the external venting hole technique, wherein a well-located venting hole decreases the amount of excess cement around the margins.[18] One of the drawbacks of this technique is porcelain fracture caused by a defect in structural integrity.[19] This technique was introduced for abutments with a screw access channel to minimize the amount of residual cement while improving retention.[20,21] Techniques minimizing the amount of cement could control the amount of excess cement, although they might also lead to the formation of marginal gaps.[22] The use of abutment replicas (either practice abutments or resin abutment replicas) to mimic the cementation procedure in vitro before actual cementation has also been recommended with good outcomes in terms of retention and minimal excess cement.[13,22] However, few studies on evaluation of the above mentioned techniques have been reported.

The purpose of the present study was to evaluate 3 techniques for cementing implant-supported restorations by assessing changes in the discrepancy (dis_change) between the restoration and abutment precementing discrepancies (predis) and postcementing discrepancies (postdis), linear roughness of the restoration marginal surface, and retention of the restoration. The null hypothesis was that no differences would be found in dis_change, linear roughness and retention among the cementing techniques.

MATERIAL AND METHODS

Twelve IACs and metal crowns with defect-free and smooth marginal surface were used in the study. Each IAC was composed of a 5.5-mm-high titanium abutment (RN synOcta Cementable Abutment; Institut Straumann AG) screwed onto a 12-mm-long stainless steel implant analog (analog for RN synOcta; Institut Straumann AG) with a 35-Ncm torque according to the manufacturer's instructions. Twelve metal crowns with loops on the superior surface (Minigold; Ivoclar Vivadent, Inc) were fabricated according to the standard laboratory protocol by using prefabricated synOcta plastic copings, and 12 resin abutment replicas (Pattern resin; GC Dental Products Corp) were made for each crown. All the surfaces of the specimens used were inspected using stereomicroscopy (model C-DSS230; Nikon), and the average marginal gap between the fabricated crowns and IACs was approximately 50 μm.

A 50-μm-thick die spacer (silver, 13 μm + yellow 7 μm + dentin 10 μm + silver 13 μm + yellow 7 μm die spacer; Yeti Dentalprodukte GmbH) was applied to the surfaces of the resin abutment replica (Fig. 1).[23] Each set of IACs, crowns, and resin abutment replicas was numbered from specimen 1 to specimen 12. Four index indentations across the margins of the crown and IAC/resin abutment replica were marked at approximately equal distances with a surgical scalpel with blade #15 under a stereomicroscope for further measurements. The 12 specimens were treated with the 3 different techniques based on the following method: the 12 specimens were assigned to 6 groups (groups A-F, 2 specimens per group), and the assigned specimens and sequences of cementation procedures for the 6 groups are shown on Table 1.

Before cementation, all elements were cleaned in an ultrasonic bath (Model VS 350; Silfradent) with distilled water for 10 minutes, wiped with alcohol, and inspected under the stereomicroscope. Each crown set on the corresponding IAC was placed in a holder (Fig. 1), and each area containing the indentation was examined using confocal microscopy (3D laser scanning microscope, VK-X100K/X200K; Keyence Corp) with a 10× objective lens. A self-adhesive universal resin cement (3M ESPE RelyX U100; 3M Deutschland GmbH) was used for all the cementation procedures according to the manufacturer's instructions.[24]

In technique 1, a certain amount of cement (approximately 8×1×0.5 mm) was evenly placed over the entire interior marginal surface (IMS) of the crown by using an explorer (23/6 Explorer; Hu-Friedy Mfg Co LLC),[25] followed by seating the crown along the long axis of the IAC with manual compression for 10 seconds. A subsequent 49-N load parallel to the long axis of the IAC was applied to the crown for 5 minutes, using a universal testing machine.[12,20,26] The cement was then polymerized for 3 seconds with a light-emitting diode at 470 nm (Elipar S10; 3M Deutschland GmbH). Excess cement was removed with an explorer, followed by light-polymerizing for 20 seconds on the margins of the specimens.[24] In technique 2, a lesser amount of cement (approximately 5×1×0.5 mm) than that used in

Figure 1. Elements used in experiments. A, IAC. B, Crown with a ring. C, Resin abutment replica with smeared die spacer. D, Assembly of crown and IAC in holder. IAC, implant-abutment complex.

technique 1 was evenly placed over the inner 2/3 of the crown IMS with an explorer, followed by seating of the crown, manual compression and loading, and light-polymerizing for 20 seconds on the margins. In technique 3, approximately twice the amount of cement used in technique 1 (approximately 16×1×0.5 mm) was evenly placed on the entire IMS of the crown. A resin abutment replica was pressed on the crown along its long axis, and excess cement was immediately wiped off with cotton gauze. The resin abutment replica was then removed along the long axis of the crown, followed by seating of

Table 1. Specimens and sequences of techniques in each group

Group	Specimens	Sequence of Techniques
A	#3, #12	T1-T2-T3- T1-T2-T3- T1-T2-T3
B	#9, #6	T1-T3-T2- T1-T3-T2- T1-T3-T2
C	#4, #11	T2-T1-T3- T2-T1-T3- T2-T1-T3
D	#2, #10	T2-T3-T1- T2-T3-T1- T2-T3-T1
E	#8, #7	T3-T1-T2- T3-T1-T2- T3-T1-T2
F	#5, #1	T3-T2-T1- T3-T2-T1- T3-T2-T1

Technique 1 (T1): small amount of cement evenly placed and excess cement removed with explorer. Technique 2 (T2): much smaller amount of cement used without excess cement removal. Technique 3 (T3): double amount of cement and use of resin abutment replica for excess cement removal before crown seating.

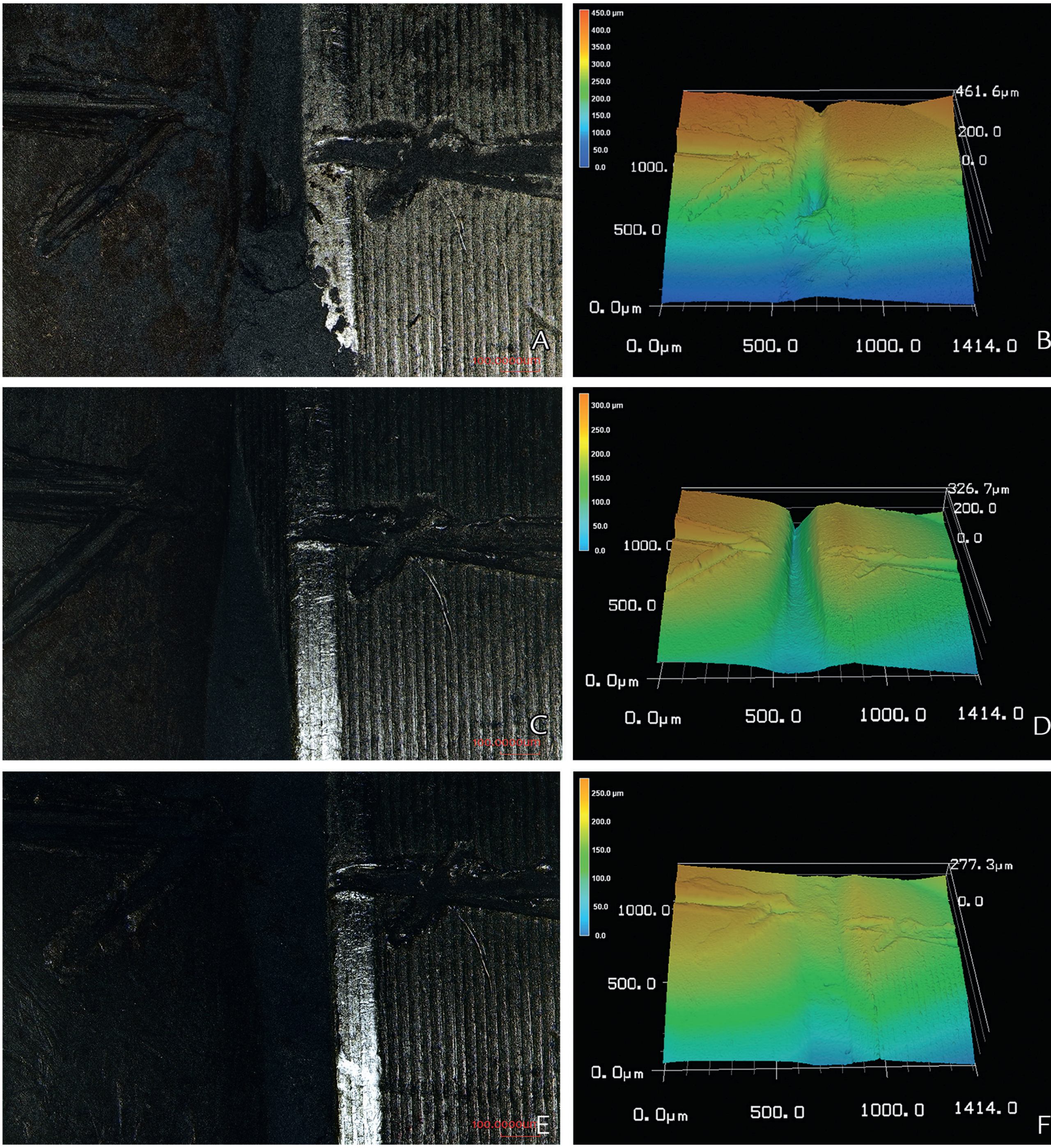

Figure 2. Confocal microscopy images of same cemented site (specimen 11, point b) and their three-dimensional reconstructed graphs for three techniques. A, B, Irregular surface with pits and crests at implant-abutment complex restoration junction with technique 1. C, D, Voids or gaps at the junction area with technique 2. E, F, smoother surface of the junction area with technique 3.

the crown, manual compression and loading, and light-polymerizing for 20 seconds at the margins.

Ten hours after cementation, specimens were subjected to 1000 thermocycles between 5°C and 55°C with a 30-second dwell time in each water bath.[27,28] The marginal area of each specimen was examined by using confocal microscopy, and then all of the measurements were conducted. To apply a different technique to the same specimen, all the elements had to be thoroughly cleaned after the previous measurement. The crowns were heated at the loop for 2 minutes with an alcohol burner and cooled in water for 1 minute; then any residual cement on the crown, IAC, and resin abutment replica was carefully removed by using an explorer and without touching the margins. All the elements were rinsed in the ultrasonic bath with distilled water for 10 minutes, wiped with alcohol, and inspected under a stereomicroscope before cementation.

The marginal gap or discrepancy before and after cementation (predis and postdis) between the crowns and IACs was measured on designated junction areas of each specimen by using analysis software (VK Analyzer; Keyence Corp), and changes in discrepancy (dis_change) after cementation were calculated by subtracting predis from postdis. The measuring areas for predis and postdis were located on the marginal edges of the crowns and IACs 100 μm from an indentation on both sides, and 3 measurements for each area were performed. Linear roughness (Ra and Rz) was used to represent the surface roughness of the junction area in the study. Ra and Rz are the 2 components of linear roughness; Ra is the arithmetic mean of the roughness curve in the direction of the designated line, and Rz is the mean of the maximum height on the roughness curve. The measuring line for Ra and Rz was designated the line parallel to the long axis of the IAC, 100 μm from both the indented margins of the crown and IAC along the designated line on the junction surface area. Three measurements for each line were also made by using the VK Analyzer. To retain the restorations after cementation, tensile strength was measured by pulling the crown from the IAC on a holder, with the universal testing machine at a crosshead speed of 0.5 mm/min.[13,29]

Ra and Rz, and tensile strength values were compared among the 3 techniques by using linear mixed models for repeated measures as a randomized complete block design, with different covariates for each technique; the order of the experiment was considered a potential covariate in the model. Predis and dis_change values were also compared among the 3 techniques by using the same model. To study the effects of the discrepancies on linear roughness and tensile strength values, dis_change was added as a covariate in the mixed models, and roughness and tensile strength values were compared among the 3 techniques. Sensitivity analyses were conducted using similar models with various covariate structures and log-transformed data for Ra; consistent conclusions were achieved. The sample size of 12 provided approximately 80% power to detect an effect size of 1.0 standard deviation difference between 2 techniques at a significance level of .025 based on paired *t* tests. The conservative Bonferroni method was used to account for simultaneous comparisons (technique 1 versus 3, and 2 versus 3) for sample size estimation. All data analyses were performed using SAS verdion 9.4 software (SAS Institute Inc). Comparisons among techniques were conducted using LSMEANS statement of the parameters in the MIXED procedure without multiple comparison adjustment.

Table 2. Estimated mean ±SE for dis_change, Ra, Rz, and tensile strength with different techniques

	Discrepancy Difference (μm)		Ra (μm)		Rz (μm)		Tensile Strength (N)	
Technique	Mean	±SE	Mean	±SE	Mean	±SE	Mean	±SE
T1	27.3	9.27	12.0	1.25	44.5	4.03	165	12.0
T2	17.1	4.70	10.2	1.90	39.9	6.72	165	6.79
T3	-1.23	3.23	4.68	1.27	19.6	4.36	194	11.5

Dis_change, change in discrepancy between implant-abutment complex and crown after and before cementation; Ra and Rz, postcementing linear roughness; SE, standard error.

RESULTS

Confocal microscopy images and their corresponding 3-dimensional reconstructed surface graphs for a selected point for the different techniques are shown in Figure 2. The images show irregular surfaces with pits and crests at the IAC-restoration junction with technique 1 and voids or gaps with technique 2, whereas the similar junction area appears smoother with technique 3. Mean and standard error values for dis_change, Ra, Rz, and tensile strength for each technique are summarized in Table 2, and multiple comparisons of these indices among the 3 techniques in Table 3. Figure 3 shows a high correlation between Ra and Rz (Pearson correlation coefficient: r=0.985; P<.05). Ra and Rz values were significantly different among the 3 techniques (P<.001 for Ra and P=.002 for Rz). Ra and Rz values with technique 3 (4.68 ±1.27 μm and 19.6 ±4.36 μm, respectively) were significantly lower than those for technique 1 (12.0 ±1.25 μm, 44.5 ±4.03 μm, respectively) and technique 2 (10.2 ±1.90 μm, 39.9 ±6.72 μm, respectively; all P<.05), whereas no significant differences were noted between techniques 1 and 2. With regard to tensile strength, the value obtained with technique 3 (194 ±11.5 N) was significantly higher than that with technique 2 (165 ±6.79 N; P<.05) and insignificantly higher than that with technique 1 (165 ±12.0 N; P>.05). No significant differences was noted between techniques 1 and 2.

No significant differences were noted in values of predis among the 3 techniques (54.5 ±4.48, 49.1 ±4.66, and 56.3 ±4.16 μm for techniques 1, 2, and 3, respectively; P>.05). The dis_change value was significantly lower with technique 3 (−1.23 ±3.23μm) than with techniques 1 and 2 (27.3 ±9.27 and 17.1 ±4.70, respectively; both P<.05), whereas no significant differences were noted between techniques 1 and 2 (P>.05). Because Ra, Rz, and tensile strength were strongly influenced by dis_change (r=0.583, 0.629, and −0.270; all, P<.05) (Fig. 4), dis_change was included as a covariate in the mixed model and the direct effects of the 3 techniques on Ra and tensile strength were reassessed (Table 4). Results indicated that

Table 3. Comparison of dis_change, Ra, Rz, and tensile strength values among 3 techniques

	Dis_change (μm)					Ra (μm)				
Technique	Mean*	±SE	*P*	Lower	Upper	Mean*	±SE	*P*	Lower	Upper
T1 vs T2	10.2	10.4	.342	-11.8	32.2	1.75	2.27	.451	-3.01	6.50
T1 vs T3	28.5	9.82	.0116	7.47	49.6	7.32	1.78	.0005	3.62	11.0
T2 vs T3	18.4	5.71	.0037	6.59	30.2	5.57	2.28	.0247	0.791	10.4

	Rz (μm)					Tensile Strength (N)				
Technique	Mean*	SE	*P*	Lower	Upper	Mean*	SE	*P*	Lower	Upper
T1 vs T2	4.61	7.84	.563	-11.8	21.1	0.529	13.7	.968	-28.4	29.5
T1 vs T3	24.8	5.94	.0004	12.5	37.2	-28.8	16.6	.0964	-63.1	5.58
T2 vs T3	20.2	8.01	.0206	3.46	37.0	-29.3	13.3	.0413	-57.3	-1.29

SE, standard error. *Mean, mean differences are shown.

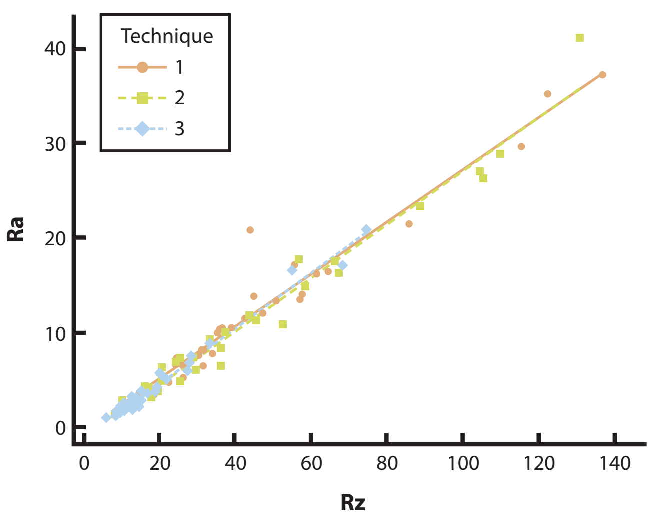

Figure 3. Scatterplot for postcementing linear roughness values (Ra and Rz) show positive correlation between Ra and Rz. r=0.985; P<.05.

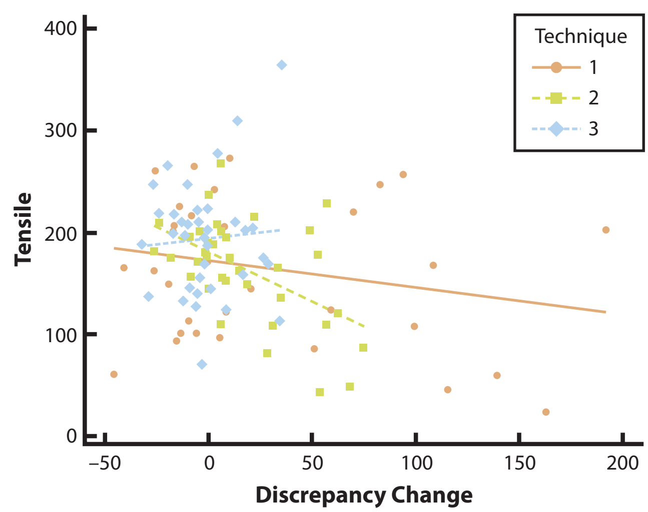

Figure 4. Scatterplot for tensile strength and dis_change values showing negative correlation between the 2 parameters. r=−0.270; P<.05. dis_change, change in discrepancy between implant-abutment complex and crown after and before cementation.

dis_change was positively associated with Ra (P<.05), whereas the significant differences in Ra values were less but persistent among the 3 techniques (P=.046); techniques 1 and 2 were associated with higher Ra values than technique 3(P<.05 and >.05, respectively) (Table 4). However, dis_change was not significantly negatively associated with tensile strength (P>.05), and no significant differences were observed among the 3 techniques (P>.05) after adjusting the effect of dis_change, although tensile strength was lower with techniques 1 and 2 than with technique 3 (both P>.05).

DISCUSSION

According to the results mentioned above, the null hypothesis was partially rejected. Compared with technique 1, technique 3 was associated with a decrease in dis_change and linear roughness at the IAC-restoration junction and an increase in tensile strength; technique 2 was not significantly different from technique 1 with regard to dis_change and linear roughness.

In the study, the amount of resin cement was determined for a balance between minimal excess cement and maximal tensile strength. Other than on the axial walls, cement was only placed on the interior margin surface area of the crown. In technique 1, a certain amount of resin cement was evenly spread, overflowed over the external margins of the crown and IAC, and removed with an explorer. In technique 2, an amount that was just sufficient to reach the external margins was used to avoid excess cement removal. In technique 3, the amount of resin cement was doubled to accommodate the space created by the die spacer and compensate for the volume caused by the shrinkage of the resin abutment replica.

Twelve specimens were observed using stereomicroscopy to ensure that no residue was left before the next treatment and that all 3 techniques were applied on every specimen to minimize individual specimen differences. To ensure that each of the 3 treatments was used on the same specimen with the same condition and

Table 4. Comparisons of Ra and tensile strength values among 3 techniques after adjusting the effect of dis_change

	Ra (μm)					Tensile Strength (N)				
Technique	Mean*	SE	*P*	Lower	Upper	Mean*	SE	*P*	Lower	Upper
T1 vs T2	0.738	1.98	.713	-3.40	4.88	3.84	14.0	.788	-25.9	33.6
T1 vs T3	4.49	1.69	.0144	0.980	7.99	-19.5	17.0	.264	-54.7	15.8
T2 vs T3	3.75	2.11	.0905	-0.645	8.14	-23.3	13.0	.0901	-50.7	4.05

SE, standard error. *Mean, mean differences are shown.

before performing another treatment, each specimen was thoroughly and carefully cleaned. A stereomicroscope was used to inspect the surface of the specimen to ensure no remaining cement or other debris. An alternative surface area would have been used for roughness measurement if additional scratches from cement removal with a metal explorer had been found. Moreover, to reduce measuring error, the measurements focused only on the junction area, mostly on the cement.

Discrepancies between the IAC and restoration before and after cementation significantly affected the dis_change. Before luting, the crown and IAC exhibited an average marginal gap of 53.3 ±1.74 μm. An 80-μm thickness for the cement film yielded has been reported as an optimal bonding strength.[30,31] The average particle size in the inorganic filler that accounts for approximately 72% of the composition of RelyX Unicem is less than 9.5 μm, which could contribute to the effects on postdis. The major setting reaction for RelyX Unicem involves radical polymerization, wherein the monomers aggregate rapidly with increasing viscosity. Early cement removal before cements set completely could avert high viscosity cement and large discrepancies in cementation.

Measurements of surface roughness include the measurement of linear roughness that measures a single line on the specimen surface and the measurement of a real roughness that measures an area of the surface. Linear roughness measurement was used in the study. A smooth surface reduces bacterial accumulation, whereas excess cement removal using sharp instruments undesirably increases the surface roughness. Alterative areas were used for the measurement of Ra and Rz on the same specimen surface if scratches were found under the stereomicroscope to minimize measurement variation from scratches. The surface roughness might be less affected if a plastic scaler rather than a metal explorer is used.[16,17]

With regard to retention, an intimate connection between the IAC and crown is essential to prevent stress concentration of tensile force. Tensile strength considerably decreases with the formation of fissures and pits. Such defects were observed with techniques 1 and 2 and resulted in decreased retention, suggesting that linear roughness is negatively associated with tensile strength. Because tensile strength is negatively influenced by postdis and dis_change, the increased retention with technique 3 was likely to be the result of a smaller discrepancy. Therefore, postdis and dis_change were included as covariates in the comparison of tensile strength among the 3 techniques. Differences exhibited the same trends but no statistical significance, which suggests that the differences in tensile strength among the 3 techniques were primarily attributed to differences in postdis and dis_change.

With regard to the choice of resin cement, those with a longer working time and greater fluidity are preferred.[22] A longer working time moderates autopolymerizing during the additional seating and dislodging steps, while greater fluidity facilitates the adequate flow of the resin cement. Another factor is the choice of abutment replica. Several methods are available for fabricating these replicas. They can either be fabricated along with the other implant elements by the manufacturers (practice abutment) or duplicated with resin or fast-setting materials (resin abutment replica).[13,22,23] The former method allows a more accurate configuration of the actual abutment to facilitate adequate spreading, while the latter method is less time consuming and more cost efficient; even if a deviation exists, it can be adjusted by the fluidity of the cement.

Conventionally, a die spacer is applied on die surfaces during the fabrication of restorations to reserve space for cement, thus facilitating a passive fit for the fabricated crown.[32] Few clinical studies involve the use of a resin abutment replica during cementation.[33] More studies on the clinical applications of these cementing techniques are needed to further verify the findings in this study.

CONCLUSIONS

Within the limitations of this in vitro study, it was concluded that the application of a resin abutment replica during the cementation of implant-supported restorations might decrease the discrepancy between the restoration and abutment, reduce the cement residue, and increase the restoration retention.

REFERENCES

1. Michalakis KX, Hirayama H, Garefis PD. Cement-retained versus screw-retained implant restorations: a critical review. Int J Oral Maxillofac Implants 2003;18:719-28.
2. Al-Omari WM, Shadid R, Abu-Naba'a L, El Masoud B. Porcelain fracture resistance of screw-retained, cement-retained, and screw-cement-retained

implant-supported metal ceramic posterior crowns. J Prosthodont 2010;19: 263-73.
3. Wittneben JG, Millen C, Bragger U. Clinical performance of screw- versus cement-retained fixed implant-supported reconstructions–a systematic review. Int J Oral Maxillofac Implants 2014;29 Suppl:84-98.
4. 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.
5. Shapoff CA, Lahey BJ. Crestal bone loss and the consequences of retained excess cement around dental implants. Compend Contin Educ Dent 2012;33: 94-6, 98-101.
6. Gapski R, Neugeboren N, Pomeranz AZ, Reissner MW. Endosseous implant failure influenced by crown cementation: a clinical case report. Int J Oral Maxillofac Implants 2008;23:943-6.
7. Linkevicius T, Puisys A, Vindasiute E, Linkeviciene L, Apse P. Does residual cement around implant-supported restorations cause peri-implant disease? A retrospective case analysis. Clin Oral Implants Res 2013;24:1179-84.
8. Pesce P, Canullo L, Grusovin MG, de Bruyn H, Cosyn J, Pera P. Systematic review of some prosthetic risk factors for periimplantitis. J Prosthet Dent 2015;114:346-50.
9. Linkevicius T, Vindasiute E, Puisys A, Linkeviciene L, Maslova N, Puriene A. The influence of the cementation margin position on the amount of undetected cement. A prospective clinical study. Clin Oral Implants Res 2013;24:71-6.
10. Oh TJ, Yoon J, Misch CE, Wang HL. The causes of early implant bone loss: myth or science? J Periodontol 2002;73:322-33.
11. Mombelli A, Lang N. The diagnosis and treatment of peri-implantitis. Periodontol 2000 1998;17:63-76.
12. Akca K, Iplikcioglu H, Cehreli MC. Comparison of uniaxial resistance forces of cements used with implant-supported crowns. Int J Oral Maxillofac Implants 2002;17:536-42.
13. Gervais MJ, Wilson PR. A rationale for retrievability of fixed, implant-supported prostheses: a complication-based analysis. Int J Prosthodont 2007;20:13-24.
14. Santosa RE, Martin W, Morton D. Effects of a cementing technique in addition to luting agent on the uniaxial retention force of a single-tooth implant-supported restoration: an in vitro study. Int J Oral Maxillofac Implants 2010;25:1145-52.
15. Gultekin P, Gultekin BA, Aydin M, Yalcin S. Cement selection for implant-supported crowns fabricated with different luting space settings. J Prosthodont 2013;22:112-9.
16. Agar JR, Cameron SM, Hughbanks JC, Parker MH. Cement removal from restorations luted to titanium abutments with simulated subgingival margins. J Prosthet Dent 1997;78:43-7.
17. Fox SC, Moriarty JD, Kusy R. The effects of scaling a titanium implant surface with metal and plastic instruments: an in vitro study. J Periodontol 1990;61: 485-90.
18. Schwedhelm ER, Lepe X, Aw TC. A crown venting technique for the ementation of implant-supported crowns. J Prosthet Dent 2003;89:89-90.
19. Loza-Herrero MA, Rivas-Tumanyan S, Morou-Bermudez E. Success and complications of implant-retained prostheses provided by the Post-Doctoral Prosthodontics Program, University of Puerto Rico: a cross-sectional study. J Prosthet Dent 2015;114:637-43.
20. Wadhwani C, Pineyro A, Hess T, Zhang H, Chung KH. Effect of implant abutment modification on the extrusion of excess cement at the crown-abutment margin for cement-retained implant restorations. Int J Oral Maxillofac Implants 2011;26:1241-6.
21. Wadhwani C, Hess T, Pineyro A, Chung KH. Effects of abutment and screw access channel modification on dislodgement of cement-retained implant-supported restorations. Int J Prosthodont 2013;26:54-6.
22. Dumbrigue HB, Abanomi AA, Cheng LL. Techniques to minimize excess luting agent in cement-retained implant restorations. J Prosthet Dent 2002;87:112-4.
23. Wadhwani C, Pineyro A. Technique for controlling the cement for an implant crown. J Prosthet Dent 2009;102:57-8.
24. da Rocha PV, Freitas MA, de Morais Alves da Cunha T. Influence of screw access on the retention of cement-retained implant prostheses. J Prosthet Dent 2013;109:264-8.
25. Lee MY, Heo SJ, Park EJ, Park JM. Comparative study on stress distribution around internal tapered connection implants according to fit of cement- and screw-retained prostheses. J Adv Prosthodont 2013;5:312-8.
26. Uludamar A, Ozkan Y, Ozkan YK. Effects of thermocycling on the retention of various cements of one-unit and three-unit fixed implant-supported restorations. Int J Oral Maxillofac Implants 2012;27:567-76.
27. Olivera AB, Saito T. The effect of die spacer on retention and fitting of complete cast crowns. J Prosthodont 2006;15:243-9.
28. Yuksel E, Zaimoglu A. Influence of marginal fit and cement types on microleakage of all-ceramic crown systems. Braz Oral Res 2011;25:261-6.
29. Hara AT, Pimenta LA, Rodrigues AL Jr. Influence of cross-head speed on resin-dentin shear bond strength. Dent Mater 2001;17:165-9.
30. Diaz-Arnold AM, Williams VD, Aquilino SA. The effect of film thickness on the tensile bond strength of a prosthodontic adhesive. J Prosthet Dent 1991;66:614-8.
31. Keith SE, Miller BH, Woody RD, Higginbottom FL. Marginal discrepancy of screw-retained and cemented metal-ceramic crowns on implants abutments. Int J Oral Maxillofac Implants 1999;14:369-78.
32. Carter SM, Wilson PR. The effects of die-spacing on post-cementation crown elevation and retention. Aust Dent J 1997;42:192-8.
33. Galván G, Kois JC, Chaiyabutr Y, Kois D. Cemented implant restoration: A technique for minimizing adverse biologic consequences. J Prosthet Dent 2015;114:482-5.

Corresponding author:
Dr Jiangzhang Liu
Department of Prosthodontics
Peking University, School and Hospital of Stomatology
22 Zhongguancun Nandajie, Haidian District
Beijing 100081
CHINA
Email: liujianzhangdr@163.com

Acknowledgments
The authors thank Drs Yijiao Zhao and Yong Wang, Center of Digital Dentistry, National Engineering Laboratory for Digital and Material Technology of Stomatology, Peking University School and Hospital of Stomatology for their valuable collaboration and loan of test instrument used in this study; and Dr Zhihui Sun for assistance.