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. However, excess residual cement is a concern. Thorough removal of the excess cement is generally a challenge, particularly with subgingival margins. Residual cement may lead to a marginal discrepancy and increase surface roughness at the junction between the restoration and implant-abutment complex (IAC). Surface roughness, together with the vulnerable connective tissues, decreases vascularity around the implants and harbors subgingival bacteria that then damage the perimplant tissue and cause the vertical destruction of the crestal bone and implant failure. Interim cement may be preferred because of easier retrievability of the restoration and excess cement removal despite low retention and high solubility. 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.
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.\textsuperscript{16,17} Cementing techniques with the following features are considered favorable: minimal residual cement to the margins.\textsuperscript{18} One of the drawbacks of this technique is decreasing the amount of excess cement around the hole technique, wherein a well-located venting hole decreases the amount of excess cement around the margins.\textsuperscript{19} One of the drawbacks of this technique is the formation of marginal gaps.\textsuperscript{20} The use of abutment replicas (either practice abutments or resin abutment replicas) to mimic the cementation procedures in vitro before actual cementation has also been recommended with good outcomes in terms of retention and minimal excess cement.\textsuperscript{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).\textsuperscript{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 in 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 RelX U100; 3M Deutschland GmbH) was used for all the cementation procedures according to the manufacturer’s instructions.\textsuperscript{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), 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.\textsuperscript{12,20} 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.\textsuperscript{24} In technique 2, a lesser amount of cement (approximately 5×1×0.5 mm) than that used in
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

![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.](image)

<table>
<thead>
<tr>
<th>Table 1. Specimens and sequences of techniques in each group</th>
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<tbody>
<tr>
<td><strong>Group</strong></td>
</tr>
<tr>
<td>A</td>
</tr>
<tr>
<td>B</td>
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<tr>
<td>C</td>
</tr>
<tr>
<td>D</td>
</tr>
<tr>
<td>E</td>
</tr>
<tr>
<td>F</td>
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</tbody>
</table>

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.
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. 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

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.
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 version 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.

**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>0.5). 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>0.05). The dis_change value was significantly lower with technique 3 (−1.23 ±3.23 μm) than with techniques 1 and 2 (27.3 ±9.27 and 17.1 ±4.70, respectively; both P<0.05), whereas no significant differences were noted between techniques 1 and 2 (P>0.05). 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

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

<table>
<thead>
<tr>
<th>Technique</th>
<th>Discrepancy Difference (μm) Mean ±SE</th>
<th>Ra (μm) Mean ±SE</th>
<th>Rz (μm) Mean ±SE</th>
<th>Tensile Strength (N) Mean ±SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>27.3 ±9.27</td>
<td>12.0 ±1.25</td>
<td>39.9 ±4.48</td>
<td>165 ±11.5</td>
</tr>
<tr>
<td>T2</td>
<td>17.1 ±4.70</td>
<td>10.2 ±1.90</td>
<td>39.9 ±6.72</td>
<td>165 ±6.79</td>
</tr>
<tr>
<td>T3</td>
<td>−1.23 ±3.23</td>
<td>27.3 ±9.27</td>
<td>17.1 ±4.70</td>
<td>165 ±12.0</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Technique</th>
<th>Mean* ±SE</th>
<th>P</th>
<th>Lower</th>
<th>Upper</th>
<th>Mean* ±SE</th>
<th>P</th>
<th>Lower</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1 vs T2</td>
<td>10.2 10.4</td>
<td>.342</td>
<td>-11.8</td>
<td>32.2</td>
<td>1.75 2.27</td>
<td>.451</td>
<td>-3.01</td>
<td>6.50</td>
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<tr>
<td>T1 vs T3</td>
<td>28.5 9.82</td>
<td>.0116</td>
<td>7.47</td>
<td>49.6</td>
<td>7.32 1.78</td>
<td>.0005</td>
<td>3.62</td>
<td>11.0</td>
</tr>
<tr>
<td>T2 vs T3</td>
<td>18.4 5.71</td>
<td>.0037</td>
<td>6.59</td>
<td>30.2</td>
<td>5.57 2.28</td>
<td>.0247</td>
<td>0.791</td>
<td>10.4</td>
</tr>
</tbody>
</table>

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

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**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.
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 that measures an area of the surface. Measurement of linear roughness that measures a single line on the specimen surface and the measurement of Ra and Rz on the same specimen surface if scratches were found under the stereomicroscope to minimize measurement variation 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.

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.22 Few clinical studies involve the use of a resin abutment replica during cementation.30 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**


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