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Cement Selection for Implant-Supported Crowns Fabricated with Different Luting Space Settings

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Keywords
Cementation; implant-supported prosthesis; luting gap; retention; luting agent.

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The authors deny any conflicts of interest.

Accepted May 2, 2012

doi: 10.1111/j.1532-849X.2012.00912.x

Abstract

Purpose: To measure and compare the retentive strength of cements specifically formulated for luting restorations onto implant abutments and to investigate the effect of varying cement gap on retention strength of implant-supported crowns.
Materials and Methods: Standard titanium abutments were scanned by means of a 3D digital laser scanner. One hundred and sixty standard metal copings were designed by a Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) system with two cement gap values (20 and 40 μm). The copings were cemented to the abutments using the following eight cements with one being the control, zinc oxide temporary cement, while the other seven were specifically formulated implant cements ($n = 10$): Premier Implant Cement, ImProv, Multilink Implant, EsTemp Implant, Cem-Implant, ImplaTemp, MIS Crown Set, and TempBond NE. The specimens were placed in 100% humidity for 24 hours, and subjected to a pull-out test using a universal testing machine at a 0.5 mm/min crosshead speed. The test results were analyzed with two-way ANOVA, one-way ANOVA, post hoc Tamhane' s T2, and student's *t*-tests at a significance level of 0.05.
Results: Statistical analysis revealed significant differences in retention strength across the cement groups ($p < 0.01$). Resin-based cements showed significantly higher decementation loads than a noneugenol zinc oxide provisional cement (TempBond NE) ($p < 0.01$), with the highest tensile resistance seen with Multilink Implant, followed by Cem-Implant, MIS Crown Set, ImProv, Premier Implant Cement, EsTemp Implant, and ImplaTemp. Increasing the cement gap from 20 to 40 μm improved retention significantly for the higher strength cements: Multilink Implant, Premier Implant Cement, ImProv, Cem-Implant, and MIS Crown Set ($p < 0.01$), while it had no significant effect on retention for the lower strength cements: EsTemp Implant, ImplaTemp, and TempBond NE ($p > 0.05$).
Conclusions: Resin cements specifically formulated for implant-supported restorations demonstrated significant differences in retention strength. The ranking of cements presented in the study is meant to be an arbitrary guide for the clinician in deciding the appropriate cement selection for CAD/CAM-fabricated metal copings onto implant abutments with different luting space settings.

Implant-supported prosthetic reconstructions can involve screw- or cement-retained restorations. The choice of cementation versus screw retention is primarily a matter of the clinician's preference.[1] Many clinicians prefer cementation of implant-supported crowns to screw fixation.[2,3] Although there is no consensus on whether one method of retention is superior to the other, cemented restorations have gained more popularity because of lower complication rates and higher fracture resistances of the veneering ceramic.[1,2,4–7] Cement retention also offers the advantages of creating a more passive fit, improved esthetics, elimination of occlusal access openings to create a more favorable occlusal surface, simplicity, and lower cost.[2,8,9] In addition to these advantages, cementation of a restoration onto an implant abutment may prevent its removal for future maintenance, which is a disadvantage.[8,10]

The ideal luting agent would provide sufficient retention to prevent loosening during normal service but allow the restoration to be removed without damage to the tissue interface, abutment, or restoration in case of the need for periodic replacement of prosthodontic components, loosening or fracture of the fastening screws, fracture of the abutments, modification of the prosthesis after loss of an implant, and evaluation of oral hygiene and tissue response.[2,3,8] Studies on luting agents used to cement the restorations onto implant abutments have been inconclusive as to which cement to use, because the study protocols vary, and the systems used have differed.[2,9,11]

Cements can be classified as permanent or provisional luting agents. Zinc phosphate, zinc polycarboxylate, glass ionomer, and self-adhesive resin cements have been preferred for permanent cementation of implant-supported restorations and used frequently as a standard of comparison for cement retention studies.[2,12,13] However, some authors recommend the use of provisional cements such as zinc oxide and eugenol cements as alternatives to ensure the retrievability of cemented implant-retained restorations without damage.[2,8,14] Their advantage in retrievability, though, is accompanied by poor physical properties, such as low tensile strength and high solubility, leading to patient dissatisfaction.[2,8] Therefore, to obtain a semipermanent fixation that provides adequate retention and yet allows retrievability, new low-strength resin cements with low solubility are being developed by manufacturers.[2,15] In addition, fewer data exist with respect to the retentive behavior of novel resin cements specifically formulated for luting restorations onto implant abutments.[14,16]

The presence of a cement gap reduces the elevation of restorations, improves the outflow of excess cement, and lowers the seating forces, resulting in a better fit and retention of the final restoration.[9,17–19] The cement gap thickness should be large enough to allow proper seating of the restoration but not so large as to cause excessive cement thickness.[20] In 1983, Grajower and Lewinstein stated that "an optimum fit" of the casting can be obtained only if the relief space allows for the cement film thickness and roughness of the tooth and casting surfaces. They also recommended a relief space of 50 μm for the thickness of the spacer to be applied on the die surface. This value includes 30 μm for the cement film as well as 20 μm for distortion of the wax pattern.[21] Furthermore, the development of Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) systems has largely eliminated the possibility of distortions during the production process. In recent years, the majority of authors have reported that the ideal cement gap thickness ranges from 20 to 40 μm.[22–26] It is also accepted that for optimal results, the cement gap should be uniform.[17] The nature of CAD/CAM copings is that they are fabricated for a '"passive fit" with the assistance of an algorithm that provides for a uniform luting space.[18] By using CAD/CAM technology, it is possible to fabricate standard implant- and/or tooth-supported metal copings with uniform but different luting space values.[18,28]

The aim of this study was to comparatively evaluate the retention strength of specifically formulated implant cements used for CAD/CAM-fabricated implant-supported crowns with two cement gap values. The hypotheses tested were that: (1) various luting agents influence the retention strength of implant-supported crowns, (2) changing luting space settings affects the decementation loads, and (3) the pattern of decementation across the two cement gaps differs for the implant cements.

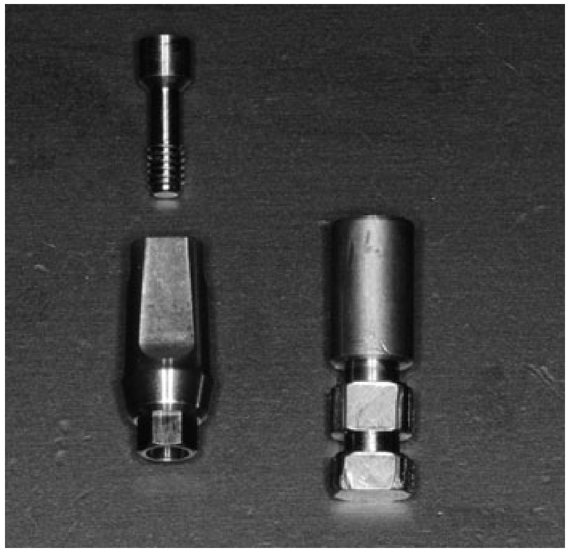

Figure 1 Biohorizons 3inOne 3.5 mm standard abutment, screw, and analog.

Materials and methods

For this study, 160 standard titanium implant abutments with a diameter of 3.5 mm and a height of 6.5 mm (3inOne, BioHorizons Inc., Birmingham, AL), and 160 standard implant analogs (3inOne) were used (Fig 1). The implant analogs were embedded in acrylic resin blocks (Meliodent, Bayer Dental, Newburg, Germany) with the aid of a dental surveyor. Each implant abutment was placed on its respective analog and torqued to 30 Ncm. The abutment screws were covered with a cotton pellet, and the access holes were filled with a temporary filling material (Cavit, 3M ESPE, Seefeld, Germany). One of the abutments was scanned by means of a 3D digital laser scanner of a dental CAD/CAM system (Dental Wings Inc. Montreal, Canada) (Fig 2). All the metal copings were designed by DWOS Software (Dental Wings Inc.) based on this scanned data. Half the copings were designed with a cement gap of 20 μm and

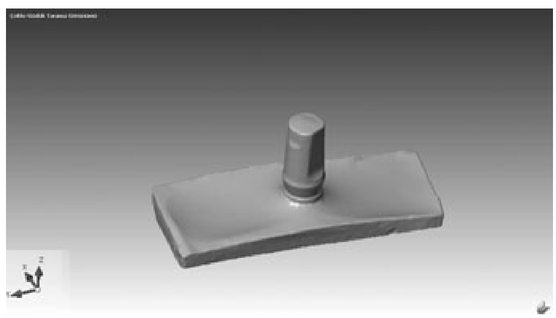

Figure 2 Scanned abutment screen by Dental Wings DWOS Software.

Table 1 Cements listed by name, type, and manufacturer

Cement name	Manufacturer's description	Manufacturer
Premier Implant Cement (PIC)	Noneugenol temporary cement for implant-retained crowns	Premier Dental Products, Plymouth Meeting, PA
ImProv (IP)	Eugenol-free acrylic resin based provisional implant cement	Alvelogro Inc., Snoqualmie, WA
Cem-Implant (CI)	Noneugenol acrylic-urethane polymer based temporary cement for implant luting	BJM Laboratories Silmet Ltd, Or-Yehuda, Israel
MIS Crown Set (MCS)	Permanent cement for implant-retained crowns	MIS Implant Technologies Ltd., Shlomi, Israel
ImplaTemp (IT)	Eugenol-free acrylic-urethane based temporary cement for implant restorations	Osseous Technologies of America, Huntington Beach, CA
EsTemp Implant (ET)	Noneugenol temporary resin cement for implant restorations	Spident Co. Ltd., Incheon, South Korea
Multilink Implant (MI)	Self-/dual-curing, two-component luting composite for the cementation of restorations on implant abutments	Ivoclar Vivadent, Schaan, Liechtenstein
TempBond NE (TB)	Zinc oxide noneugenol provisional cement	Kerr Corporation, Orange, CA

the other half with a gap of 40 μm. The coping designs were created by a standardized metal thickness of 0.5 mm and a metal ring attached to the occlusal surface to be used during pull-out testing. The obtained files were sent to a Selective laser sintering/selective laser melting (SLS/SLM) machine (Hint ELs rapidPro, Hint-ELs, Griesheim, Germany), where the CoCr powder was sintered/melted by selectively consolidating successive layers of powder material on top of each other with thermal energy supplied by a focused and computer-controlled laser beam. After fabrication, the internal surface of each coping was airborne-particle abraded with 50 μm aluminum oxide. One hundred sixty abutments were randomly divided into two cement gap groups. Copings were fitted to the randomly selected abutments for both cement gap groups using a silicone disclosing medium (Fit Checker, GC Corp, Tokyo, Japan) and investigated with a light microscope (Olympus BX 60, Olympus Optical Co Ltd, Tokyo, Japan) under 5× magnification for proper fitting. The internal surfaces of the copings and the abutment surfaces were steam cleaned before cementation.

Eighty copings within each cement gap group were randomly allocated to eight groups, yielding 10 copings per implant cement. Cementation was performed with eight luting agents ($n = 10$) (Table 1). All cements were used according to the manufacturers' recommendations. Copings were seated with finger pressure and then placed under a controlled axial load of 5 kg for 10 minutes at room temperature. After 10 minutes, excess cement was removed with a plastic curette. After cementation, the specimens were allowed to set for 24 hours and then placed in distilled water for at least 24 hours before pull-out testing. Subsequently, the specimens were subjected to a pull-out test with a universal testing machine (Autograph AG-X, Shimadzu Corporation, Kyoto, Japan) at a 0.5 mm/min crosshead speed. The load required to de-cement each coping was recorded in Newtons, and mean values for each group were determined. The statistical analysis was performed using the Statistical Package for Social Sciences for Windows software package (SPSS 15.0.1 Inc., Chicago, IL). Comparisons of quantitative data were conducted with two-way ANOVA, one-way ANOVA, and post hoc Tamhane's T2 tests between groups.

Table 2 Effect of cement type and cement gap on tensile test results

	F	*p*
Cement	48.074	0.001**
Cement gap	10.837	0.013*
Cement-Cement gap	10.080	0.001**

Note: Two-way ANOVA test.
*$p < 0.05$.
**$p < 0.01$.

Student's *t*-test was used for pairwise intragroup comparisons of parameters. The data were evaluated with a significance level of $p < 0.05$.

Results

Two-way ANOVA revealed a significant influence of the cement type ($p < 0.01$), and the cement gap ($p < 0.05$) on retention. Moreover, the effect of the cement type and cement gap size together was found to be statistically significant on retention of copings ($p < 0.01$) (Table 2).

The mean retention values and standard deviations are summarized in Table 3 for all groups. For both cement gap groups, statistical analysis revealed significant differences in retention strength across the cement groups ($p < 0.01$). For the 20-μm group, MI cement showed a significantly higher decementation load than other seven cements ($p < 0.01$) whereas TB had the lowest pull-out test results between all cements ($p < 0.01$) (Fig 3). The results for IT cement were significantly lower than those for PIC, IP, CI, and MCS cements ($p < 0.01$). ET cement showed significantly lower test results than those for PIC, IP, CI, and MCS cements ($p < 0.01$, $p < 0.05$). The test results of PIC, IP, CI, and MCS cements were not significantly different for the 20-μm group ($p > 0.05$) (Tables 3 and 4).

For 40-μm, similar to the 20-μm group, MI cement showed a significantly higher decementation load than the other seven cements ($p < 0.01$) whereas TB had the lowest pull-out test results between all cements ($p < 0.01$; Fig 4). IT and ET cements

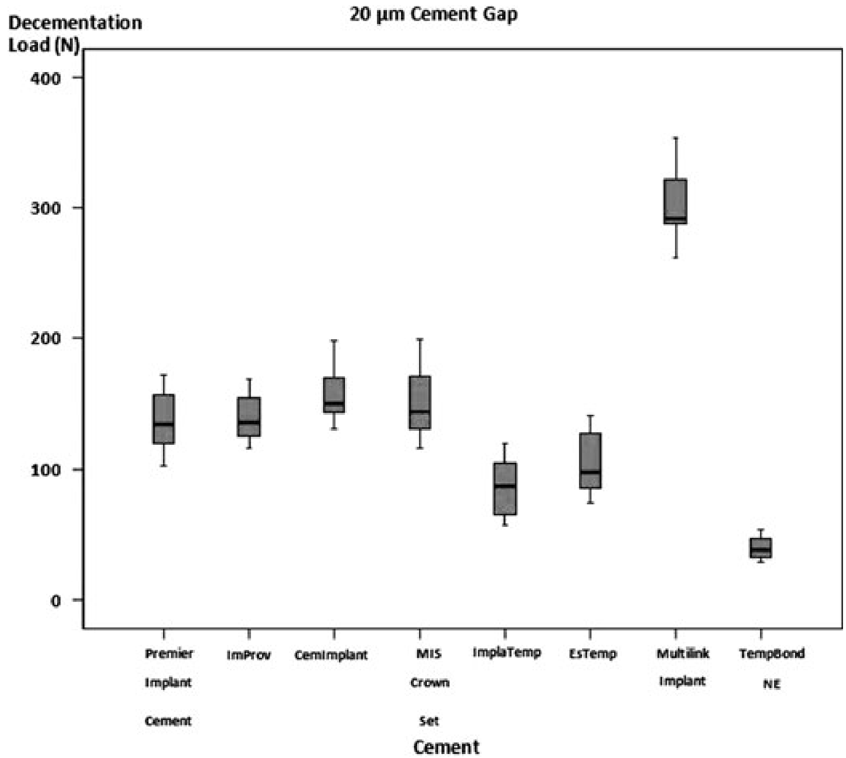

Figure 3 Median pull-out test results for 20 μm cement gap group.

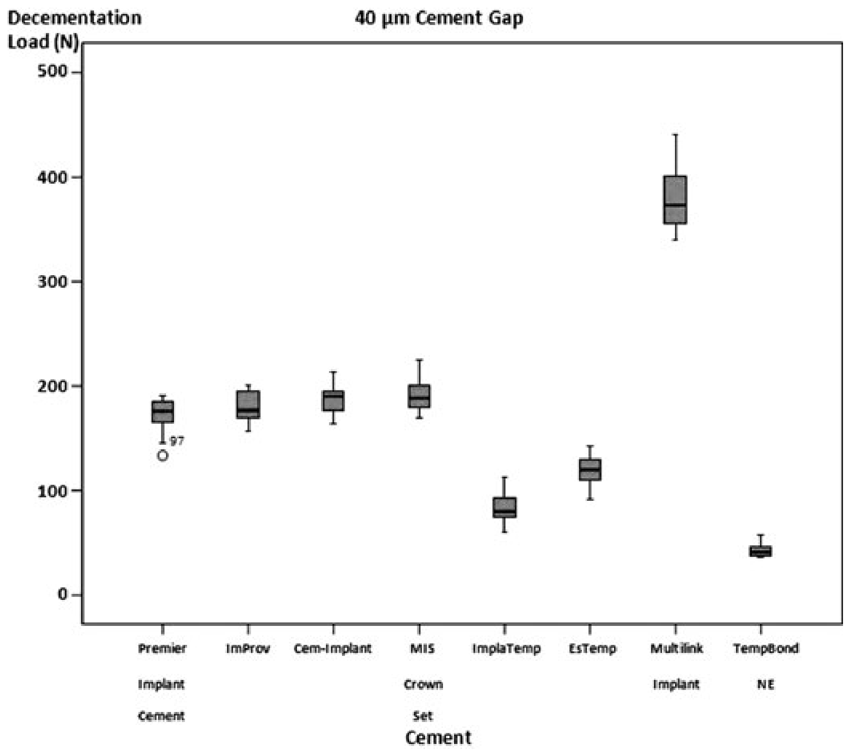

Figure 4 Median pull-out test results for 40 μm cement gap group.

showed significantly lower test results than those for PIC, IP, CI, and MCS cements ($p < 0.01$). The test results of PIC, IP, CI, and MCS cements were not significantly different in the 40-μm group ($p > 0.05$) (Tables 3, 4).

Only for IT cement were the pull-out test results at a cement gap of 40 μm lower than those at a gap of 20 μm. For the other seven cements, the pull-out test results of the 40-μm group were higher than those of the 20-μm group. This difference

Table 3 Evaluation of pull-out test results

Cement	Decementation load (N) 20 μm Mean ± SD	40 μm Mean ± SD	†p
PIC	136.97 ± 21.75	171.35 ± 17.55	0.001**
IP	139.50 ± 17.90	179.54 ± 15.03	0.001**
CI	155.79 ± 18.38	187.30 ± 15.05	0.002**
MCS	150.28 ± 24.55	190.75 ± 16.32	0.001**
IT	86.16 ± 22.16	83.63 ± 16.06	0.752
ET	105.66 ± 23.12	118.57 ± 14.83	0.120
MI	301.60 ± 28.44	378.85 ± 31.50	0.001**
TB	39.65 ± 8.08	42.72 ± 6.54	0.318
‡p	0.001**	0.001**	

†Student's *t*-test.
‡One-way ANOVA test.
** $p < 0.01$.

between the pull-out test results of 20- and 40-μm cement gap groups was statistically significant for PIC, IP, CI, MCS, and MI cements ($p < 0.01$), but not for IT, ET, and TB cements ($p > 0.05$) (Table 3).

Discussion

In this in vitro study, the retention strength of luting agents used for CAD/CAM-fabricated metal copings were evaluated with two cement gap values. An increasing number of luting agents described for use with implant-supported prostheses are being introduced into the market. Evidence on the selection, classification, and indications of cement materials is sparse. This study was conducted to classify the existing resin cements specifically formulated for implant-supported restorations, including the previously produced and the novel ones in relation to retention.

The rationale for the use of provisional cements for cement-retained implant restorations was originally based on the concept of providing ease of retrievability. Nevertheless, the use of these relatively "weak" cements may result in inadequate retention and patient dissatisfaction.[29] According to our results, cements can be classified to offer the clinician a progression of retentive strengths from which to choose. ET and IT showed significantly lower test results than the other five resin-based cements. Depending on this data, ET and IT with the lowest test results among all resin cement groups, may be used as an alternative to conventional provisional cements such as TB. The authors concluded that CI, MCS, IP, and PIC, demonstrating similar test results, can be classified as semipermanent cements and may be recommended for common use, as they offer the advantages of retrievability and adequate retention at the same time. In accordance with our results, previous studies found that IP shows more retention than PIC, stating that this difference is not statistically significant.[9,15,29] Comparing the results with other studies was not possible due to the lack of evidence for the other five resin cement groups. MI showed the highest retention values among all cement groups. These values were similar to those of definitive cements such as zinc phosphate, glass-ionomer, resin-modified glass ionomer,

Table 4 Post hoc test results

Cement	Decementation load (N) 20 μm p	40 μm p
PIC/IP	1.000	0.999
PIC/CI	0.602	0.522
PIC/MCS	0.995	0.253
PIC/IT	0.001**	0.001**
PIC/ET	0.067	0.001**
PIC/MI	0.001**	0.001**
PIC/TB	0.001**	0.001**
IP/CI	0.669	0.999
IP/MCS	0.999	0.937
IP/IT	0.001**	0.001**
IP/ET	0.018*	0.001**
IP/MI	0.001**	0.001**
IP/TB	0.001**	0.001**
CI/MCS	1.000	1.000
CI/IT	0.001**	0.001**
CI/ET	0.001**	0.001**
CI/MI	0.001**	0.001**
CI/TB	0.001**	0.001**
MCS/IT	0.001**	0.001**
MCS/ET	0.004**	0.001**
MCS/MI	0.001**	0.001**
MCS/TB	0.001**	0.001**
IT/ET	0.737	0.001**
IT/MI	0.001**	0.001**
IT/TB	0.001**	0.001**
ET/MI	0.001**	0.001**
ET/TB	0.001**	0.001**
MI/TB	0.001**	0.001**

Note: Tamhane's T2 test.
*$p < 0.05$.
**$p < 0.01$.

or zinc polycarboxylate cements used in previous studies.[8,30] The pull-out test results for MI were significantly higher than all other cements, meaning that this cement may be recommended when permanent cementation of implant-supported restorations is mandatory. Luting restorations with MI onto abutments that have sufficient retention/resistance form may complicate retrievability. Also, it may cause problems working with multiple unit bridges. In the case of insufficient retention with short and increasingly tapered abutments, MI may be more appropriate for the cementation of implant-supported restorations, especially for single crowns.

All cements used in the study, except MI, were self-cure cements. MI is a dual-cure cement that may be used for cementing all-ceramic restorations onto zirconia abutments. Because this study used metal restorations instead of all-ceramic ones, test results reflected the mean tensile strength of MI cement polymerized with only the self-cure mode. The tensile strength of MI will probably increase while luting all-ceramic implant-supported restorations with dual-cure polymerization mechanisms.

This study is unique in its use of cements that have been specifically formulated for implants. In other studies, a few number of cements specifically formulated for implant-supported restorations were compared with other commonly used luting agents. Currently, there is no published study in which seven implant cements have been compared. The results of the previous studies are mostly in accordance with our results, in that resin cements have greater retention than conventional provisional cements and IP shows more retention than PIC.[9,15,29] Most luting cements, except resin-based cements, are prone to tensile failure because of their brittle nature.[16] This may be why TB has the lowest pull-out test results among the groups.

According to its manufacturer, MCS is a permanent cement for implant-supported restorations. The results from this study showed that tensile test results for MCS were not significantly different from those of PIC, IP, and CI, described as temporary cements by the manufacturers. Also, MCS demonstrated significantly lower test results than MI. Therefore, it was classified as a semipermanent cement based on pull-out test results.

The cement failure mode was generally adhesive in nature, occurred at the cement/abutment interface with the remnant cement remaining mostly within the metal copings. Cements used in the study were easily removed from abutment surfaces except one. MI showed high retention to the abutment surface, indicating that it may cause periimplant tissue problems unless meticulous cementation procedure is applied. The authors concluded that excess cement removal from subgingival margins may be difficult with MI.[9,31] In addition, misfitting and/or decreased retention may result after recementation over the abutment, if the cement remains permanently attached to the abutment surface.[9]

Previously the cement gap size has not been considered as a parameter for implant-retained metal-based restorations; however, it is widely accepted that cement thickness is also a factor affecting the durability of the cement, leading to retention of the restoration.[19] In a review article, Taylor et al stated that cement-retained implant superstructures may be completely passive because of the 25- to 30-μm space provided for the cement, a concept used for many decades in traditional fixed prosthodontics.[32] Ebert et al found that increasing the cement gap from 30 to 60 μm had a detrimental effect on cement durability and lead to some problems when choosing resin cements.[33] Wu and Wilson also reported that for optimal seating, the cement gap must be more than 30 μm.[19] Different authors have preferred to use different cement thicknesses in publications.[4,8,9,16,29,30,33–36] For most, the cement gap ranged from 20 to 40 μm.[4,8,9,16,29,30,34] We chose these values based on studies accepting that an optimum cement thickness of 20 to 40 μm is generally specified to facilitate complete seating of the restoration and to allow for the film thickness of the cement.[24–26,37,38]

In our study, increasing the cement gap from 20 to 40 μm led to significantly greater retention for higher strength cements (PIC, IP, CI, MSC), whereas the difference was not significant for lower strength cements (ET, IT, TB). A possible reason for this result is that alterations in film thickness, viscosity, and cohesive strength related to the size or shape of the filler particles affected the optimum retention properties and retrievability. Previously, Carter and Wilson found an increased failure stress with an increased number of die spacer layers for crowns luted with zinc phosphate cements.[36]

Variations resulting from the measuring and mixing of luting agents may alter tensile bond strength.[16] In most previous studies, conventional mixing techniques with inspection methods that may reduce cement quality (owing to changes in the mixing ratio) have been preferred.[2,4,8,9,15,16,27,29,30,34,39,40] To overcome these problems, the cements used in the study were all applied with automix syringe dispensers.

The fabrication of implant-supported restorations involves many clinical and laboratory procedures that require a high degree of precision. Small errors can occur at each stage of the fabrication procedure, which will contribute to positional distortion of the prosthesis relative to the implants.[2] In most previous studies in which the retrievability of cement-retained implant-supported crowns was evaluated, standard fabrication techniques for metal-based implant superstructures were used. These techniques may give misleading results because distorsions are possible at any stage.[2,4,8,9,15,16,28–30,34,39] For standardization of copings, some authors have preferred to use standard burn-out caps fabricated by the implant manufacturer.[4,9,11,30,34] However, investing and casting procedures probably contribute similarly to distortion. Furthermore, it is not always possible to know the amount of cement space needed for a passive fit with the burnout caps. To eliminate any possibility of distortion and guarantee the standardization of copings, the CAD/CAM technique was used to fabricate the specimens. Nonetheless, each abutment/coping pair was used only once to avoid the possibility of surface contamination resulting with from casting misfit. Some authors have used the same copings for pull-out testing.[15,18,30,34,40] This may yield misleading results on the retentive behavior of cements.

Other authors have noted the high standard deviations reflective of the unpredictable behavior of these cements, as well as the difficulties in study design.[9,13,31,41] Our pull-out test results showed standard deviations lower than those in previously published studies. As mentioned previously, this is presumably because of strictly standardized protocol at every stage; however, in this study, there were some limitations such as inability to accurately simulate the intraoral environment and the specific physical conditions imposed. As thermocycling was not applied, the effects of degradation that might be seen in the clinical situation over time were not considered here. Some authors have found that thermocycling had a minimal effect on retention when cementing restorations onto abutments. It has also been found that resin-based provisional cements were the least affected group among all provisional cements by thermocycling because its coefficient of thermal expansion is so close to that of metal components.[29] However, these limitations were viable for all specimens; therefore, they were assumed to have no effect on the accuracy of the test analysis from a retention viewpoint, as long as the abutment/coping pairs were compared with each other in the same study. Another drawback of the study is the use of a pure tensile test. In a clinical situation, it is likely that other forces also contribute to crown decementation.[34] However, the tensile test was adopted in our study to allow comparisons with previous studies.

At present, it is difficult to quantify the amount of retention necessary for retrievability, while guaranteeing the long-term endurance of the prosthesis.[42] To be able to make recommendations about cement selection, further clinical studies are needed to confirm our results by comparing more cements, varying abutment properties, evaluating multiple-unit prostheses, and imitating the oral environment with improved methods.

Conclusion

Within the limitations of this study, the following conclusions were drawn:

(1) The luting agents in the study can be classified as follows;

(a) Provisional cements: EsTemp Implant, ImplaTemp, TempBond NE
(b) Semipermanent cements: Premier Implant Cement, ImProv, Cem-Implant, MIS Crown Set
(c) Permanent cement: Multilink Implant

(2) Increasing the gap size from 20 to 40 μm improved retention significantly for higher strength cements (Premier Implant Cement, ImProv, Cem-Implant, MIS Crown Set, Multilink Implant).
(3) Varying the gap size had no significant effect on retention for lower strength cements (EsTemp Implant, ImplaTemp, TempBond NE).
(4) Luting agents described by manufacturers as implant cements demonstrated different retention properties. Therefore, the clinician must determine the appropriate cement according to the patients' needs. The ranking of cements presented in the study is meant to be an arbitrary guide for the clinician in deciding the appropriate cement selection for CAD/CAM-fabricated metal copings onto implant abutments.

Acknowledgment

The authors would like to thank Fatih Uysal from UMG Uysal Medical, Local Distributor of BioHorizons Inc., Birmingham, AL, for his valuable assistance and supplying implant parts used in this study.

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