

RESEARCH

Effect of luting space and cements on retention of implant supported crowns fabricated by laser sintering*

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ABSTRACT

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Background: The aim of this study was to evaluate the retention strength of five different cements used for implant supported crowns with two cement gap values.

Methods: Standard titanium abutments were scanned by means of a 3D digital laser scanner. 100 standard metal copings were designed by a CAD/CAM system with two cement gap values (20 and 40µm). The copings were cemented to the abutments using the following five cements (n=10). Poly F (PF), GC FujiCEM (GCF), Rely X (RX), MIS Crown Set(MCS) and Multilink N (MN). The specimens were placed in 100% humidity for 24 hours then specimens were thermal cycled 1000 times. After thermal cycling specimens were 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, followed by multiple comparisons using Tamhane tests ($\alpha=0.05$).

Results: Statistical analysis revealed that significant differences were observed among cement groups ($p<0.05$). PF and MN had the highest and the least mean retentive strength, respectively. No significant difference was found between RX and MCS. Increasing the cement gap from 20 to 40 µm improved retention significantly for each cement group ($p<0.05$).

Conclusion: 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.

KEYWORDS

Cementation, cement gap, implant-supported prosthesis, retention

ÖZ

Lazer sinterize yoluyla üretilen implant destekli kronların tutuculuklarında siman aralığının ve simanların etkisi

Amaç: Bu çalışmanın amacı iki farklı siman aralığı ile yapılan implant destekli kronlar için kullanılan beş farklı simanın tutuculuk mukavemetini değerlendirmektir.

Gereç ve Yöntemler: Standart titanyum dayanaklar dijital bir 3D lazer tarayıcı aracılığıyla tarandı. 100 standart metal alt yapı bir CAD/CAM sistem aracılığıyla iki farklı siman aralığı değerinde (20 ve 40 µm) tasarlandı. Alt yapılar beş farklı siman kullanılarak yapıştırıldı (n=10). Poly F (PF), GC FujiCEM (GCF), Rely X (RX), MIS Crown Set(MCS) and Multilink N (MN). Örnekler 24 saat bekletildikten sonra 1000 devir termal siklus uygulandı. Termal siklustan sonra örnekler universal test cihazında 0.5 mm/dk. hızla çekme testine tabi tutuldu. Test sonuçları iki yönlü varyans analizini takiben tamhane testleri kullanılarak çoklu karşılaştırmalarla analiz edildi ($\alpha=0.05$).

Bulgular: İstatistiksel analiz değerlendirildiğinde siman grupları arasında anlamlı farklılıklar görüldü ($p<0.05$). PF ve MN sırasıyla en yüksek ve en düşük tutuculuk kuvveti ortalamasına sahipti. RX ve MCS arasında anlamlı farklılık bulunmadı. 20 den 40µm ye artan siman aralığı, her siman grubu için tutuculuğu anlamlı ölçüde artırdı ($p<0.05$).

Sonuç: Çalışmada sunulan simanların klinisyenler için, implant dayanakların üzerine üretilen CAD/CAM metal alt yapılar için uygun siman seçimini belirlemede isteğe bağlı bir rehber olması amaçlanmıştır.

ANAHTAR KELİMELER

İmplant-destekli protez, siman, siman aralığı, tutuculuk

Dental implants have been used successfully for tooth replacement over the last few decades. Nevertheless, some controversy exists regarding the method for connecting the prosthesis to the implant.¹⁻³ Implant-supported prostheses can be retained by screws or cement, depending primarily on the clinician's

preference.⁴⁻⁵ Although no consensus has been reached regarding the superiority of any method of retention, cement retention is more popular because of lower complication rates and higher fracture resistance of veneering ceramics.⁶⁻¹¹ It also offers the advantages of passive fit, improved

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esthetics, favorable occlusal surface by eliminating occlusal access openings, simplicity, and reduced cost.^{7,12,13} One disadvantage is that it may prevent removal of the prosthesis for maintenance.^{11,14}

The ideal luting agent prevents loosening of the prosthesis during normal service. However, it allows removal without damage to the tissue interface, abutment, and restoration for replacement due to loosening or fracture of the fastening screw or fracture of the abutment, modification of the prosthesis after loss of the implant, and evaluation of oral hygiene and tissue response.^{4,7,12} Zinc phosphate, zinc polycarboxylate, glass ionomer, and self-adhesive resin cements are preferred for permanent cementation of implant-supported restorations and frequently used as standards for studies of cement retention.¹⁵⁻¹⁷ However, the published studies on luting agents for such prostheses are inconclusive because of variability of experimental protocols and systems.^{4,13,15}

The luting space reduces elevation of the restoration during cementation, improves outflow of excess cement, and lowers seating force, enhancing fit and retention of the prosthesis.^{18,19} It should be large enough to allow proper seating of the restoration without increasing the cement film thickness²⁰; it should also be uniform.¹⁸ Grajower and Lewinstein²¹ stated that "optimum fit" of a casting can be achieved only if the relief space allows for the cement film thickness and roughness of the tooth and casting surfaces. They recommended a relief space of 50 μm to be maintained on the die, including 30 μm for the cement film and 20 μm to compensate for distortion of the wax pattern. However, the development of computer-aided design and manufacturing (CAD/CAM) systems has largely eliminated distortions during fabrication. In recent years, most authors have reported that the ideal luting space ranges from 20 to 40 μm .²²⁻²⁶

Direct metal laser sintering (DMLS) is a promising technology to avoid distortions inherent to casting procedures. It involves the use of a high-power laser source, such as carbon dioxide laser, to fuse small particles of powdered alloy. Each dental structure is built in layers from the occlusal surface to the margins by scanning cross-sections in a three-dimensional CAD file of the framework designed after abutment digitization.²⁷⁻³⁰ Standard implant- and/or tooth-supported metal copings can be fabricated for passive fit by using an algorithm that ensures a uniform luting space.^{31,32}

MATERIALS AND METHODS

Specimen preparation

In this study, 100 standard titanium implant abutments with a diameter of 3.7 mm and height of 5 mm (Implant Direct Sybron International, Thousand Oaks, CA) and 100 standard implant analogs were used. The analogs were embedded in acrylic resin blocks (Meliodent, Bayer Dental, Newburg, Germany) with the aid of a surveyor. Each abutment was placed on its respective analog and torqued to 30 Ncm. One abutment was scanned by three-dimensional digital laser in a dental CAD/CAM system (Dental Wings, Inc. Montreal, Canada). All copings were designed by DWOS Software (Dental Wings, Inc.) using the scanned data. The design included a luting space of either 20 or 40 μm ($n=50/\text{group}$), standardized coping thickness of 0.5 mm, and a metal ring on the occlusal surface for pullout testing. The obtained files were transferred to a DMLS device (Concept Laser GmbH, Lichtenfels, Germany).

For DMLS, the temperature of the device was gradually increased to 1650°C. The process began by sintering a 20- μm layer of cobalt-chromium powder onto a stainless steel platform in an argon atmosphere. and then, 20- μm increments of the alloy powder were sintered from the bottom up until the copings were completed. The 500-W ytterbium-doped fiber laser was precisely controlled in the x- and y-coordinates, maintaining exceptional tolerances (± 0.0254). The copings were cooled to ambient temperature (decreasing at 9°C/min) inside the furnace. The internal surface of each coping was air-abraded with 50- μm aluminum oxide particles.

Copings with different luting spaces were randomly selected, fitted to abutments, and examined under a light microscope (Olympus BX60, Olympus Optical Co. Ltd., Tokyo, Japan) at $\times 5$ magnification for proper fit. The internal surfaces of all the copings and abutment surfaces were steam-cleaned before cementation.

Cementation, thermocycling, and pull-out testing

The copings in each luting space group were randomly allocated to five equal cement subgroups ($n=10/\text{subgroup}$) (Table 1): Poly F (PF), GC FujiCEM (GCF), Rely X (RX), MIS Crown Set (MCS), and Multilink N (MN). All the cements were used according to the manufacturers' recommendations. The copings were seated with finger pressure and placed under a controlled axial load of 5 kg for 10 min at room temperature. Excess cement was removed with a curette. Thereafter, the specimens were stored in distilled water at 37°C for 24 h. To simulate the oral environment, the specimens were subjected to 1000 cycles of thermocycling between 5°C and 55°C, with a 30-s dwell time before pullout testing.

Table 1.**Cements types and brands used in this investigation**

Material	Type	Chemical Composition	Manufacturer
Rely X U200 (RX)	Self adhesive resin	Base Paste: Methacrylate monomers containing phosphoric acid groups, methacrylate monomers, silanated fillers, initiator components, stabilizers, rheological additives Catalyst paste: Methacrylate monomers, alkaline (basic) fillers, silanated fillers, initiator components, stabilizers, pigments, rheological additives	3MESPE, Deutschland, GmbH, Germany
Multilink N (MN)	Self-etch resin	Monomer matrix: dimethacrylate and HEMA, Inorganic fillers: barium glass, ytterbium trifluoride, spheroid mixed oxide	Ivoclar Vivadent, Schaan, Liechtenstein
GC FujiCEM (GJF)	Resin modified glass ionomer cement, self cured	Paste A: fluoroaluminosilicate glass, HEMA, dimethacrylate, pigment, initiator Paste B: Polyacrylic acid, distilled water, silica powder, initiator	GC Dental Corp, Tokyo, Japan
Poly F (PF)	Zinc polycarboxylate	Zinc oxide, magnesium oxide, polyacrylic acid	Dentsply, Weybridge, UK
MIS Crown Set (MCS)	Self cure resin	Permanent cement for implant-retained crowns	Mis Imp Tech Ltd., Osseous Technologies of America, Huntington Beach, CA

Pullout tests were performed with a universal testing machine (TSTM 02500, Elista Ltd. Şti., Istanbul, Turkey) at a 0.5-mm/min crosshead speed. The load required to fracture the cement was recorded in newtons, and mean values of each subgroup were calculated.

Statistical analysis

SPSS Statistics for Windows version 15.0.1 (SPSS, Inc., Chicago, IL) was used for all analyses. Data were compared by one- and two-way analysis of variance (ANOVA) followed by post hoc Tamhane's test. The significance level was set as $p < 0.05$.

RESULTS

Two-way ANOVA revealed a significant influence of the luting agent ($p < 0.000$) and luting space ($p < 0.000$) on retention of the copings. Their combined effect was also significant ($p < 0.004$) (Table 2).

Table 2.**Effect of cement type and cement gap on pull-out test results**

Source	F	Sig
Cement	3823,1	0
Cement Gap	201,49	0
Cement*Cement Gap	4,129	0,004

Two-way ANOVA test ($p < 0.05$)

Table 3 summarizes the mean fracture loads and standard deviations. Significant differences were noted among the cement subgroups within each luting space group. In the 20- μ m group, the PF and MN subgroups had the highest and lowest mean fracture loads, respectively ($p < 0.000$). No significant difference was found between the RX and the MCS subgroups. The GCF subgroup ($p < 0.003$) showed superior values to all except the PF subgroup (Table 3).

Table 3.**Means and standad deviations (SD) of forces required to decementation of the crowns**

Cement	20 μ m (Mean $\pm$ SD)	40 μ m (Mean $\pm$ SD)	P (ANOVA)
Rely X U200	211.53 $\pm$ 7.19 ^a	241.74 $\pm$ 11.99 ^A	0
Multilink N	168.67 $\pm$ 13.80 ^b	194.55 $\pm$ 14.61 ^B	0,032
GC FujiCEM	431.10 $\pm$ 18.54 ^c	475.21 $\pm$ 19.20 ^C	0,003
Poly F	597.06 $\pm$ 12.74 ^d	654.82 $\pm$ 18.53 ^D	0
MIS Crown Set	206.92 $\pm$ 5.21 ^a	244.78 $\pm$ 7.60 ^A	0

*Different letters indicate statistically significant difference ($p < 0.05$)

Concerning the 40- μ m group, the PF subgroup showed significantly higher mean fracture load than the other subgroups ($p < 0.000$), whereas the MN subgroup had the lowest mean fracture load ($p < 0.032$). The GCF subgroup showed a significantly higher value than the RX and MCS subgroups ($p < 0.003$), which were again not significantly different. Increase in the luting space from 20 to 40 μ m significantly increased the fracture load in every cement subgroup.

DISCUSSION

In this study, the retentiveness of five luting agents for DMLS-fabricated copings with two luting spaces was evaluated by pullout tests. The failure mode was generally adhesive in nature and occurred at the cement–abutment interface; residual cement was noted within most copings. The individual and combinatorial effects of the luting agent and luting space on retention were found to be significant, partly validating the hypothesis.

PF was the most retentive, as shown by Mansor.³³ The reason for this finding is that polycarboxylate cements react with metal oxides of abutments and copings and form a chemical bond.³⁴ Further, freeze-dried polycarboxylate acid chains in the powder component of PF are initiated by water addition. When the powder is surplus, the initiation reaction becomes so intense that large agglomerates of filler particles are formed and act as cotter bolts between the coping and the abutment.³⁵

GCF was less retentive than PF. Resin-modified glass ionomer cements adhere to metal by chelating metallic ions, but retentiveness may be lowered by early water contact, resulting in matrix dissolution.^{36,37} RX and MCS yielded similar results; they can be classified as semipermanent cements and are recommended for common use, as they offer the simultaneous advantages of retrievability and adequate retentiveness. According to its manufacturer, MCS is a permanent cement for implant-supported restorations.

Although the bond strength of MN was considerably lower than the values of PF, GCF, RX, and MCS, the retentiveness of all the cements is adequate when a minimum tensile load of 200 N is used to determine clinical success.³⁸ Differences in the application method may have influenced the results: resin cements are highly technique sensitive and require additional steps unlike conventional cements.³⁹ The lower retentiveness of MN than RX may be explained by porosity and incomplete polymerization. The presence of residual acidic monomers near the adhesive interface may create weak areas and jeopardize adhesion.⁴⁰

Previously, the luting space was not considered as a parameter for implant-retained metal-based restorations; now, it is widely accepted as a factor affecting cement durability and thus retention of such restorations.¹⁹ In a review, Tylor et al.³ stated that cement-retained implant superstructures may be completely passive because of the 25–30 μm space provided for the cement, a concept used in traditional fixed prosthodontics. Ebert et al.⁴¹ found that increase in the luting space from 30 to 60 μm has a detrimental effect on cement durability and is problematic when resin cements are chosen. Wu and Wilson¹⁹ also reported that for optimal seating, the luting space must be larger than 30 μm . In most studies, the luting space ranged from 20 to 40 μm .^{8,12,13,33,41} These

values were chosen in the present study because a cement film thickness of 20 to 40 μm is generally considered optimal for complete seating of a restoration.^{24–26} The finding of improved retentiveness of the cements with the increased luting space of 40 μm may be explained by the fact that cement film thickness, viscosity, and cohesive strength are related to size or shape of filler particles and affect retentiveness and retrievability.

Thermocycling simulates thermal changes in the oral cavity.⁴² It has been used for evaluating retentiveness of luting agents for metal components¹³, bond strengths of luting agents to an implant system⁴³ and microleakage associated with luting agents.⁴⁴ GaRey et al.⁴⁵ found that thermocycling has minimal effect on retentiveness of resin cements. This finding may be attributed to the low solubility of resin cements compared with other luting agents.⁴⁶ Squier et al.¹³ thermocycled specimens between 5.1°C and 56.1°C for 24 h before tensile testing and found that zinc polycarboxylate was the most retentive cement while glass ionomer and eugenol-free zinc oxide had similar retentiveness. The results are similar to those the present study. However, no specimens without thermocycling were tested, so the effect of thermocycling on retentiveness could not be examined. Future studies need to determine the effect of thermocycling on retentiveness of different cements.

The fabrication of implant-supported restorations involves many clinical and laboratory procedures requiring a high degree of precision. Small errors can occur at each stage of fabrication and contribute to positional distortion of the prosthesis relative to the implant.⁷ In most previous studies of the retrievability of cement-retained implant-supported crowns, standard fabrication techniques for metal superstructures were used. These techniques may give misleading results because distortions are possible at any stage.^{7,8,12,33,47–52} For standardization of copings, some authors preferred to use standard burnout caps fabricated by the implant manufacturer.^{8,13,15,33,47,51} However, investing and casting procedures probably contribute similarly to distortion. Furthermore, the luting space needed for passive fit with burnout caps is not always known. To guarantee standardization of copings, the CAD/CAM technique was used to fabricate specimens in this study. Nonetheless, each abutment–coping pair was used only once, avoiding the possibility of surface contamination

due to casting misfit.

A standardized protocol was followed at every stage; however, some limitations exist, such as inability to simulate the oral environment accurately and the specific physical conditions imposed. The pullout test design represented special clinical situations only. Slow-acting dislodging forces may occur with sticky food bolus intraorally. Given the limitations, no particular cement can be recommended for luting metal alloys on titanium abutments. The perfect luting agent for implant-supported restorations should offer clinicians the opportunity to vary the level of retentiveness depending on the clinical situation. In some cases, retrievability is indicated, so the luting agent should be easily and completely removable from the abutment or restoration surface. Further clinical studies are needed to confirm these results by comparing a variety of cements, varying abutment properties, evaluating multi-unit prostheses, and imitating the oral environment with improved methods.

CONCLUSIONS

In conclusion, both the luting agent and the luting space may affect retention of DMLS-fabricated implant-supported crowns. Increasing the luting space to 40 μm may improve retention when higher-strength cements are used. The findings serve as an arbitrary guide to appropriate cement selection for enhanced retention of such restorations.

Conflict of interest

Ozgun Yusuf Ozyilmaz, Ceyda Akin and Mujde Sevimay declare that they have no conflict of interests.

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.

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