The Effect of Thermal Cycling and Air Abrasion on Cement Failure Loads of 4 Provisional Luting Agents Used for the Cementation of Implant-Supported Fixed Partial Dentures

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Purpose: *To investigate the effects of thermal cycling and surface roughness of metal implant abutments and the intaglio surface of the copings on the retentive properties of 4 provisional luting agents commonly used in the cementation of implant-retained fixed partial dentures (FPDs).* ***Materials and Methods:*** *A 2-unit implant-retained FPD and a 4-unit implant-retained FPD were fabricated using gold-palladium alloy. The abutments used were 5 mm in height. The FPDs were cemented with 4 commonly used provisional luting agents and thermocycled for 700 cycles from 5°C to 36°C to 55°C and were then subjected to tensile strength testing. After thermal cycling, the intaglio surfaces of the same FPDs and the abutments were air-abraded with 50 µm* Al_2O_3 *particles. FPDs were cemented using the same provisional cements, and after 24 hours of storage in 100% humidity, tensile strength tests were performed. Descriptive statistics, 2-way analysis of variance, Friedman's 2-way ANOVA, and Tukey's HSD test (α = .05) were performed.* ***Results:*** *Both thermal cycling and air abrasion had a significant effect (P < .001) on the retentive values of all cements tested. A noneugenol provisional cement (Nogenol) exhibited the lowest mean retentive value after both thermal cycling and air abrasion for both the 2- and 4-unit FPD models. The urethane resin provisional cement (Improv) exhibited the highest mean retentive strength for both the 2- and 4-unit FPDs after thermal cycling and air abrasion treatments.* ***Conclusions:*** *Thermal cycling had a detrimental effect on the retentive properties of all cements tested. Air abrasion significantly improved the cement failure loads of the provisional luting agents used in the study and seems to be an effective way of increasing the retention of implant-retained FPDs.* INT J ORAL MAXILLOFAC IMPLANTS 2007;22:569–574

Key words: *air abrasion, dental cements, implant-supported prostheses, thermal cycling*

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Presented at the 11th Meeting of the International College of Prosthodontists, May 25–28, 2005, Crete, Greece.

Restorations may be connected to implants through screw or cement retention.[1–4] The primary advantage of screw retention is the ability to retrieve a prosthesis when necessary.[5] Cement retention offers the advantages of creating a more passive fit, improved esthetics, and elimination of occlusal access openings to create a more favorable occlusal surface. To ensure retrievability of cemented implant-retained restorations, the use of provisional cements has been suggested as an alternative to that of definitive ones.[6,7] This proposal was based on the assumption that provisional cements present lower retentive strength properties than permanent cements.[8] Recent laboratory findings support this suggestion.[9]

Although there is some published material[10–12] on the retentive strength of both definitive and provisional cements when used with natural teeth and crowns, there is not a large volume of information regarding the generalizability of these results to metal implant components. A previous study[13] has

Table 1 Provisional Luting Agents Tested		
Cement no.	Brand	Manufacturer
1	Temp Bond	Kerr, Romulus, MI
2	Temp Bond NE	Kerr, Romulus, MI
3	Nogenol	GC America, Alsip, IL
4	Improv	Nobel Biocare, Yorba Linda, CA

Fig 1 The 4-unit implant-retained FPD.

demonstrated that the retentive strength of provisional cements used with implant components can vary. In addition, the effects of thermal cycling and surface roughness of the abutments and crowns have been mainly investigated for natural teeth, while there has been only 1 study which has examined thermal- and cycle-loading of implants.[14–17]

The purpose of this study was to investigate the effects of thermal cycling and surface roughness of the metal implant abutments and the intaglio surface of the copings on the retentive properties of 4 provisional luting agents.

MATERIALS AND METHODS

Two blocks (4 × 8 × 2 cm) of autopolymerizing transparent resin (Ortho resin, Caulk/Densply, Milford, DE) were constructed. Implant sites were prepared in the resin blocks with a slow-speed handpiece mounted on a milling machine to ensure parallelism. Two 3.75 × 15-mm machined-surface endosseous implants (Nobel Biocare, Göteborg, Sweden) were placed in the first of the 2 blocks (block A). Four 3.75-mm machined-surface endosseous implants were placed in the other block (block B).

The distance between the 2 implants in block A was 14 mm, the approximate distance between a maxillary first premolar and a maxillary first molar. The 4 implants in block B were placed in a straight line with 7 mm interimplant distance.

Plastic retentive elements (nonsegmented castables; Lifecore Biomedical, Chaska, MN) were sprued, invested with Fujivest (GC, Tokyo, Japan), and cast in a high-gold palladium alloy (Olympia, Heraeus Kulzer, Armonk, NY). Each fitted abutment casting was paired with an implant. Each abutment was then cut with a separating disk to a height of 5 mm. After the fastening screws were tightened to 32 Ncm, the screw access openings were filled with light-curing composite resin (Z 250, 3M, St Paul, MN) flush with the top of the abutment shoulder. A 2-unit fixed partial denture (FPD) was waxed to fit the 2 retentive elements in block A, and a 4-unit FPD was waxed to fit the 4 retentive elements in block B in the same manner. To maintain consistent cement thickness, the plastic prefabricated waxing sleeves accompanying each retentive element were used for fabrication of the FPD copings. This provided an approximate space of 40 μm between the opposing walls of the retentive element and the waxing sleeve. A 3-mm-diameter cylindric plastic rod was used to connect the copings. A wax loop was incorporated into the design of each FPD (Fig 1). Then the FPDs were sprued, invested with Fujivest (GC, Tokyo, Japan), and cast using the same high-gold palladium alloy used for fabrication of the retentive elements. FPD castings were divested, placed in an ultrasonic cleaner, and inspected under a magnification of 10× (Olympus BH-2, Olympus Optical, Tokyo, Japan) for surface irregularities. Positive internal irregularities were removed with a no. 1 or no. 2 round bur. Marginal adaptation was 60 ± 20 μm for all castings. Castings were then steam cleaned for 10 seconds and allowed to air dry.

The provisional luting agents used in this study are presented in Table 1. Each provisional luting agent was mixed according to the manufacturer's instructions, and a quantity of 0.01 mL, measured by means of an insulin syringe, was used for each unit of the FPD. The cement was applied to the intaglio surfaces of the castings as evenly as possible by a single operator. Then the FPDs were seated immediately with finger pressure, followed by a controlled axial load of 5 kg, which was applied for 10 minutes.

Thermal Cycling

After 10 minutes, the excess cement was removed with a curette, and the FPDs were stored in 100% humidity at 37°C for another 50 minutes. The FPDs were then thermocycled. Every thermal cycle lasted 80 seconds and consisted of 15 seconds of immersion of the FPDs in each of the 4 tanks filled with distilled water in temperatures of 36°C, 5°C, 36°C, and 55°C.[18,19]

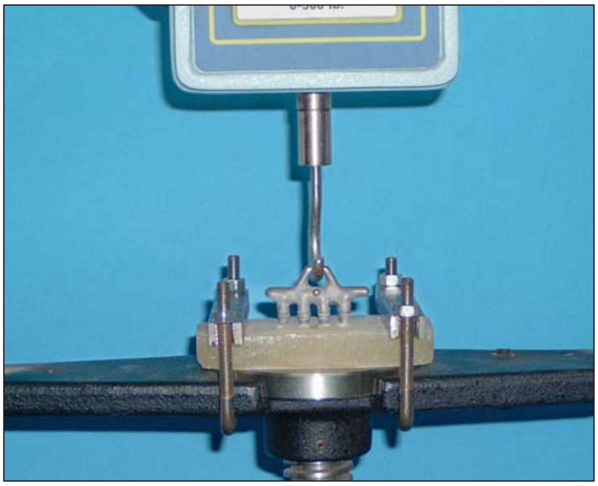

Fig 2 *(left)* The Ametek Accuforce III tensile testing apparatus.

Fig 3 *(above)* The 4-unit FPD secured to the testing machine by means of 2 C-clamps.

Seven hundred cycles were performed. After thermal cycling, each FPD was placed in an Ametek mechanical testing instrument (Accuforce III; Ametek, Mansfield & Green Division, Paoli, PA). This testing machine applied a uniaxial tensile force at a crosshead speed of 1 mm per minute by means of a hook mounted on a 500-lb load cell (Fig 2). The hook of the testing machine exerted force on the loop of the FPD, while the resin blocks were secured on the instrument by 2 C-clamps (Fig 3). After each tensile test, the FPDs and the resin blocks with the retentive elements were placed in a cement removal solution (L&R Manufacturing, Brussels, Belgium) in an ultrasonic unit for 15 minutes. The specimens were dried and visually inspected to ensure complete removal of the luting agent. Ten cementations and thermal cyclings were performed for each provisional cement, giving a total of 40 readings each for the 2-and 4-unit FPDs.

Air Abrasion

After the thermal cycling experiment, both the intaglio surfaces of the FPDs and the retentive elements were air-abraded with 50 μm Al_2O_3 at a maximum pressure of 2.5 to 3 bars. After the cementation procedure, as previously described, the FPDs were stored in 100% humidity at 37°C for another 23 hours and 50 minutes. Excess cement was removed with a curette before testing. The tensile force testing was performed as previously described. Ten cementations were made for each provisional cement, giving a total of 40 readings each for the 2- and 4-unit FPDs.

Statistical Analysis

A 2-way analysis of variance (ANOVA; $\alpha = .05$) was performed to study the effects of different provisional luting agents and thermal cycling, as well as the effects of different cements and air abrasion on cement failure modes. These analyses were performed for both the 2- and the 4-unit FPDs. It was noted that the assumption of normal distribution of cement failure loads across treatments and materials was incorrect for both models. Thus, a Friedman's 2-way ANOVA test was performed. Finally, Tukey's highly significant difference (HSD) test ($\alpha = .05$) was carried out to determine the significant differences between the materials.

The results of a previous study[13] conducted by the authors were statistically combined with those of this study.

RESULTS

The 2-way ANOVA tests ($\alpha = .05$) revealed that while thermal cycling reduced the mean cement failure loads of the provisional luting agents, air abrasion significantly increased the retentive strengths of all cements tested.

Table 2 Mean ± SD Cement Failure Loads (in kg) and Standard Deviations for the FPD Models

	2 units			4 units		
Cement	No treatment	Thermocycling	Air abrasion	No treatment	Thermocycling	Air abrasion
Temp Bond	15.99 ± 3.10[*]	12.70 ± 1.22[§]	27.05 ± 2.03[||,¶]	37.52 ± 3.87[#]	22.03 ± 1.69	50.96 ± 2.99
Temp Bond NE	23.25 ± 3.39[†,‡]	7.62 ± 0.64	28.21 ± 2.32[¶]	38.21 ± 2.31[#,a]	17.75 ± 0.98	56.14 ± 3.90
Nogenol	12.46 ± 3.95[§]	3.01 ± 0.38	15.88 ± 1.41[*]	29.51 ± 4.12	9.15 ± 0.62	37.47 ± 2.45[#]
Improv	24.60 ± 3.61[‡,||]	20.69 ± 1.72[†]	91.32 ± 2.81	43.67 ± 3.74	40.45 ± 2.25[a]	148.33 ± 2.78

Mean cement failure loads with matching symbols do not differ statistically according to Tukey's HSD test (α = .05). All other differences between similar models were significant.
Mean cement failure loads with the same color code do not present statistically significant differences according to Tukey's HSD test (α = .05).

Table 3 Retentive Value Decrease (Mean ± SD) After Thermocycling

	2 units			4 units		
Cement	No treatment	Thermocycling	Decrease (%)	No treatment	Thermocycling	Decrease (%)
Temp Bond	15.99 ± 3.10	12.70 ± 1.22	20.57	37.52 ± 3.87	22.03 ± 1.69	41.28
Temp Bond NE	23.25 ± 3.39	7.62 ± 0.64	67.22	38.21 ± 2.31	17.75 ± 0.98	53.54
Nogenol	12.46 ± 3.95	3.01 ± 0.38	75.84	29.51 ± 4.12	9.15 ± 0.62	68.99
Improv	24.60 ± 3.61	20.69 ± 1.72	15.89	43.67 ± 3.74	40.45 ± 2.25	7.37

A significant difference ($P < .001$) was noted for both the 2-unit and the 4-unit models with respect to thermal cycling. The strengthening effect of air abrasion was significant ($P < .001$) for both models.

Tukey's HSD tests ($\alpha = .05$) were performed for both the thermal cycling and the air abrasion treatment. These tests were executed for the 2- and the 4-unit FPD models (Table 2).

Nogenol exhibited the lowest mean retentive values after thermal cycling and after air abrasion for both the 2-and 4-unit FPD models. Improv exhibited the highest mean retentive strength for both the 2- and 4-unit FPDs in both thermal cycling and air abrasion treatments. After thermal cycling the mean values for the 2- and 4-unit FPDs were 20.69 and 40.45 kg, respectively, while after air abrasion of the abutments and the intaglio surfaces of the castings the mean retentive values were 91.32 and 148.33 kg. Temp Bond NE presented higher cement failure loads than Temp Bond when the FPDs were not subjected to any treatment. However, after thermal cycling Temp Bond NE displayed significantly lower retentive values when compared to Temp Bond. When used with air-abraded castings and abutments, Temp Bond NE presented higher retentive values than Temp Bond. These observations apply for both the 2- and 4-unit FPDs. Nogenol and Temp Bond NE—which are both noneugenol provisional cements—appeared to be more negatively affected by the thermal cycling treatment than Temp Bond and Improv (Table 2).

For the 2-unit FPD model, the retentive values of Temp Bond after thermal cycling and of Nogenol with no treatment were not statistically different, according to Tukey's HSD test ($\alpha = .05$). Also, Improv after thermal cycling and Temp Bond NE with no treatment did not present statistical differences and were categorized in the same group. Similar results for these two provisional cements were drawn for the 4-unit FPD model (Table 2). Decrease in cement failure modes for the 2-unit model ranged from 15.89% for Improv to 75.84% for Nogenol. For the 4-unit model the retentive values decreased from 7.37% for Improv to 68.99% for Nogenol (Table 3). All cements tested presented a cohesive type of failure after thermal cycling.

Regarding retentive values after the air abrasion of the abutments and the intaglio surfaces of the castings, Tukey's HSD test ($\alpha = .05$) revealed no statistically significant differences between Nogenol after air abrasion and Temp Bond with no treatment. Also, Improv with no air abrasion treatment and Temp Bond after air abrasion did not present statistically significant differences. Temp Bond and Temp Bond NE after air abrasion did not present statistical differences either. Regarding the 4-unit FPD model, Tukey HSD test showed that Temp Bond and Temp Bond NE with no treatment and Nogenol after air abrasion did not present statistically significant differences (Table 2).

Increase in retentive values for the 2-unit model ranged from 21.3% for Temp Bond NE to 271% for

Table 4 Retentive Value Increase (Mean ± SD) After Air Abrasion

	2 units			4 units		
Cement	No treatment	Air abrasion	Increase (%)	No treatment	Air abrasion	Increase (%)
Temp Bond	15.99 ± 3.10	27.05 ± 2.03	69.0	37.52 ± 3.87	50.96 ± 2.99	35.8
Temp Bond NE	23.25 ± 3.39	28.21 ± 2.32	21.3	38.21 ± 2.31	56.14 ± 3.90	46.9
Nogenol	12.46 ± 3.95	15.88 ± 1.41	27.4	29.51 ± 4.12	37.47 ± 2.45	26.9
Improv	24.60 ± 3.61	91.32 ± 2.81	271.0	43.67 ± 3.74	148.33 ± 2.78	239.0

Improv. For the 4-unit model the retentive values increased from 26.9% for Nogenol to 239% for Improv (Table 4).

DISCUSSION

This study was conducted using parallel-sided abutments with a height of 5 mm. Parallel-sided abutments offer more retention than abutments with a 6- or 8-degree taper. Although the use of tapered abutments would have replicated the clinical situation better, parallel-walled abutments were used to more closely mimic a study design from previous research conducted by the authors. In this study, both the castings of the FPDs and the retentive elements were reused, in keeping with results demonstrated by GaRey et al.[17]

Thermal cycling of the cement-retained FPDs has been employed to simulate 1 of the factors present in the oral environment that might affect the retentive properties of the provisional luting agents. Exact reproduction of the cyclic thermal fluctuations that take place in the oral cavity is impossible, since these largely depend on eating and drinking habits. However, since clinical trials are costly, time consuming, and difficult to design, laboratory thermal cycling is a good alternative to evaluate how thermal stresses influence cement failure modes of the tested cements. This study demonstrated that thermal cycling is a significant factor in the reduction of the retentive properties of the provisional cements tested. In this study, noneugenol cements such as Nogenol and Temp Bond NE were more affected by thermal cycling than the other 2 cements. Conversely, Improv, a urethane resin provisional cement, was the least affected by the thermal cycling procedure. The coefficient of thermal expansion differed between the casting alloys and the luting agents. The gold palladium alloy exhibits a coefficient of thermal expansion of 13.5×10^{-6}/°C,[20] while the zinc oxide eugenol cements present a coefficient of thermal expansion of 35×10^{-6}/°C. The resin composites have a coefficient of thermal expansion of 14 to 50×10^{-6}/°C.[20,21] During thermal cycling procedures, dimensional changes occur in both the metal components and the provisional luting agents. Since the noneugenol cements of this study demonstrated decreased retentive properties after thermal cycling, it may be speculated that their coefficient of thermal expansion is not matched to that of the metal components. Conversely, Improv, which is a resin cement, presents a small reduction of its retentive properties, probably because its coefficient of thermal expansion is close to that of the metal components.[21] Thus, in the case of Improv, the dimensional changes that occurred during the thermal cycling tests were probably minimal. Differential thermal changes may induce crack propagation within the provisional luting agent and changing gap dimensions, which pump fluids in and out of the gaps.[18,22–24] Since all supporting literature refers to restorations cemented on natural teeth, further research is required on the use of provisional cements with restorations supported by metallic implant components.

A previous study conducted by the authors demonstrated that selection of a provisional luting agent is essential in achieving suitable retention for cemented implant restorations. From the results of this study, it seems that air abrasion of the abutments and the intaglio surfaces of the castings is also an important factor. Pomes et al[25] have suggested that the surface texture of the casting influences the retention of the restoration, while Kaufman et al[26] and Lorey[27] have suggested that the surface roughness of the prepared teeth results in an increase in retention of cemented restorations. This increase is the result of mechanical interlocking of the cementing medium with the roughened tooth surface. The current study demonstrates that this principle applies also for metal implant components and provisional luting agents. All cements tested demonstrated an increase in retentive values following air abrasion. From the results of this study, air abrasion appears to have a stronger effect on retentive properties than the provisional luting medium itself.

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. This situation may present a dilemma to the clinician, as a permanent cement may reduce prosthesis dislodgment but compromise retrievability, whereas a provisional luting agent offers the advantage of retrievability but may result in inadequate retention. The current study confirms that air abrasion of the abutments and the intaglio surfaces of the castings of provisionally cemented implant-retained FPDs enhances the retention without compromising retrievability.

CONCLUSIONS

Within the limitations of this in vitro study it was concluded that:

1. Thermal cycling had a detrimental effect on the retentive properties of all cements tested.
2. Air abrasion significantly increased the cement failure loads of the provisional luting agents used in the study and seems to be an effective way of increasing the retention of implant-retained FPDs.
3. Nogenol exhibited the lowest mean retentive values after thermal cycling and after air abrasion for both the 2- and 4-unit FPD models.
4. Improv exhibited the highest mean retentive strength for both the 2- and 4-unit FPDs after both the thermal cycling and air abrasion treatments.

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