Comparison of 7 Luting Protocols and Their Effect on the Retention and Marginal Leakage of a Cement-Retained Dental Implant Restoration

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Purpose: *To determine the cement bond strength and marginal leakage of castings cemented to implant abutments.* ***Materials and Methods:*** *Fifty-six titanium abutments and castings were divided into 7 groups (n = 8), 1 for each cement. Castings were cemented to abutments using 1 of 3 resin-based cements (RES, RES-B, and RES-B-P), a resin-modified glass ionomer (GI), a polycarboxylate cement (PCB), an acrylic urethane cement (UDM), or a zinc phosphate cement (ZP). Specimens were placed in 100% humidity at 37°C for 24 hours. Specimens were subjected to compressive load cycling followed by thermal cycling; they were then immersed for 24 hours in 0.5% basic fuchsin. Castings were removed with an Instron universal testing machine with a crosshead speed of 0.125 cm/min. Leakage was visually graded from 0 (no leakage) to 2 (leakage extended beyond the lower half of the internal surface of the casting). Failure load (FL) was analyzed with analysis of variance and Scheffe's test ($\alpha = .05$). Chi-square was used to analyze leakage ($\alpha = .05$).* ***Results:*** *Cements were categorized by FL into 4 statistically unique groups: (1) RES-B-P (351 N) and GI (337 N); (2) ZP (245 N) and RES-B (241 N); (3) PCB (107 N); and (4) RES (63 N) and UDM (55 N). Leakage was greater for the PCB group than for the other groups (7 of 8 specimens demonstrated leakage; $P < .01$). Three ZP specimens demonstrated leakage. UDM and RES each had 1 specimen with leakage. RES-B-P, RES-B, and GI showed no leakage.* ***Conclusions:*** *Luting agents designated by the manufacturer as provisional cements demonstrated lower resistance to removal, regardless of material type. Luting agents described by manufacturers as "permanent" differed in resistance, with resin cements being most resistant, followed by zinc phosphate and polycarboxylate cements. Provisional cements demonstrated leakage comparable to higher-strength materials.* INT J ORAL MAXILLOFAC IMPLANTS 2006;21:587–592

Key words: *cement, compressive loading, dental implants, marginal leakage, thermal cycling*

Many current implant systems have abutments onto which cast restorations may be affixed by screws or cements. Cement retention has a number of advantages; however, cementation of a cast restoration onto an implant abutment may prevent its removal for future maintenance. Retrievability of the restoration may be also be advantageous to evaluate implant loading, esthetics, occlusion, tissue response, and screw loosening prior to permanent cementation.[1]

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Cement selection is of primary importance. The ideal cement 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. Such a cement would also provide good marginal sealing. Many cements in use today were developed to provide bonding to natural tooth surfaces. However, subsequent to the success of dental implants, they have also been used for cementation of definitive and interim prostheses to metal or ceramic surfaces associated with implant-supported restorations.

Cements may be regarded as permanent or provisional luting agents.[1,2] Zinc phosphate cement has long been used for permanent cementation and has

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Table 1 Cements and Mixing Protocols Used

Proprietary material	Group	Material type	Manufacturer's designation	Manufacturer	Mixing protocol
C&B resin cement and All-Bond 2	RES-B-P	Resin	Permanent	Bisco, Schaumburg, IL	6-mm length of base and accelerator
C&B resin cement and All-Bond 2 without primer "B"	RES-B	Resin	Permanent	Bisco, Schaumburg, IL	6-mm length of base and accelerator
Provilink	RES	Resin cement for implants	Provisional	Ivoclar Vivadent, Amherst, NY	6-mm length of base and accelerator
Advance	GI	Resin-modified glass ionomer	Permanent	Denstply-Caulk, Milford, DE	3 scoops of powder and 4 drops of liquid
Durelon	PCB	Zinc polycarboxylate	Permanent	3M-ESPE, St Paul, MN	1 scoop of powder and 2 drops of liquid
ImProv	UDM	Acrylic urethane	Provisional	Steri-Oss, Yorba Linda, CA	6-mm length of base and accelerator
Fleck's zinc phosphate	ZP	Zinc phosphate cement	Permanent	Mizzy, Cherry Hill, NJ	1 scoop of powder and 5 drops of liquid

been used frequently as a standard of comparison for cement retention studies.[2–12] However, partly because of concerns regarding leakage and adhesion to substrate, other cements have been introduced.[2]

Cements with lower tensile bond strength, such as low-tensile-strength resin, zinc oxide, and eugenol cements, have been used as provisional cements.[13] The bonding strength of a material may be reduced by the addition of lubricants and variations in mixing protocols. In addition to the cement used, conditions of loading, thermal stress, contamination, geometrical configuration, fabrication technique, and the use of multiple abutments may act in concert to affect the retrievability of a prosthesis.[14,15]

Marginal leakage is also an important consideration when selecting a cement.[16–18] Leakage around the margins of crowns is dependent on a number of issues, among which are the cement solubility and dimensional changes, film thickness, adherence to substrate, and poor adaptation of the restoration to the abutment.[19–24] Marginal leakage created by wash-out of luting material can lead to dead spaces, the accumulation of toxins, and inflammation of tissue surrounding the implant, especially if the margin is located in the subgingival area.[16]

Studies examining marginal leakage around cemented crowns are often performed by methods that render further mechanical testing difficult.[22,25] Various dyes and isotopes as well as lipopolysaccharides[26] and soaking protocols are employed in leakage testing; one common example is the immersion of specimens in basic fuchsin dye.[27–29] The use of subjective scales when quantifying leakage is common.[29–31]

Compressive loading[32,33] and coefficients of thermal expansion that vary between cements and restorative materials may affect both retentive strength and marginal leakage. Test conditions simulating intraoral conditions to evaluate cementation strength should be considered. GaRey and associates[14] noted that the combined effect of loading and thermal cycling was more pronounced than that produced by either loading or thermal stress alone.

Few data exist with respect to tensile failure and marginal leakage of cement-retained implant restorations under simulated clinical conditions, especially with respect to newer resin-based or acrylic urethane cements. The purpose of this study was to examine retention and assess leakage of castings cemented to implant abutments subjected to conditions of load and thermal cycling.

MATERIALS AND METHODS

Seven luting protocols using 6 different cements were tested in this study (Table 1). The cements included resin-based cements (RES-B-P, RES-B, and RES), a resin-modified glass ionomer (GI), a polycarboxylate cement (PCB), an acrylic urethane cement (UDM), and a zinc phosphate cement (ZP). In the RES-B-P group, the luting protocol was modified, ie, an adhesive primer component was omitted. ZP was used to provide a reference point as a well-known standard with a long history of use.

Fifty-six as-manufactured Steri-Oss titanium alloy 3.8HL Straight Esthetic abutments (Steri-Oss) with laboratory implant analogs were divided into 7 different groups (8 implants per group). The abutment used in this study had a lower facial margin than lingual margin. It had a length of 10 mm with a 3-degree taper.

An abutment was attached to an implant analog, and a piece of platinum foil 25 μm (0.001 inch) thick was closely adapted to the abutment surface as a die

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Fig 1 *(Left)* An abutment attached to a laboratory implant analog. A piece of platinum foil 25 μm (0.001 inch) thick was adapted onto the abutment surface as a die spacer.

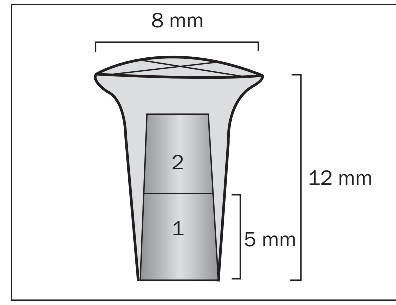

Fig 2 *(Right)* A cross-sectional view of the specimen. Castings (light gray) were cemented onto abutments (dark gray). Marginal leakage grades 1 and 2 correspond to areas denoted in the solid area.

spacer[21,34,35] (Fig 1). A mold of this abutment-analog assembly was made with silicone material (Redu-it; American Dental Supply, Easton, PA) and poured in microstone gypsum material (Whip-Mix, Louisville, KY). The stone model was used to fabricate a conical-shaped wax pattern 12 mm high with a flat 8-mm-diameter occlusal surface (Fig 2). An impression of this pattern and stone abutment was fabricated with silicone material. Using a split-mold technique, 56 identical wax crown patterns were fabricated.

The wax patterns were sprued, invested with Jelenko phosphate-bonded investment material (Heraeus Kulzer, Hanau, Germany), and cast with a silver-palladium alloy (Electra; Ivoclar Williams, Amherst, NY) at 1400°F (760°C). Castings were retrieved and steam cleaned (Pro-Craft II Steamer Cleaner; Ivoclar Vivadent, Amherst, NY), and all internal nodules were removed with a no. 2 round bur.[34] Fit of the castings to the abutments was evaluated with disclosing medium (Fit-Checker; GC Corporation, Tokyo, Japan) at 3.75× magnification (Orascopic, Middleton, WI).[26,34] The internal surface of each casting was modified with airborne-particle abrasion using 50-μm-particle-size aluminum oxide (Jelenko). Each casting was cleaned with distilled water and dried.

Implant analogs were connected to each of the 56 abutments with titanium screws and tightened with a 35-Ncm torque wrench (Steri-Oss). Screw access openings were filled with Fermit-N (Ivoclar Vivadent).[5] These 56 abutment-analog assemblies were stabilized within brass mounting rings using acrylic tray resin (Coe Tray Plastic; GC America, Alsip, IL).

Cementation of the castings was performed with the aid of an experienced dental assistant, who mixed the luting agents following the manufacturer's instructions. The castings (Fig 2) were seated quickly with hand pressure; this was followed immediately by placement of a 19.6-N compressive load (2 kg weight) directed axially onto the specimen. A customized holder with an acrylic base was made to retain the orientation of the 2 kg weight used. Each specimen and 2 kg weight was stored at 37°C and 100% humidity. One hour after cementation, the 2 kg weight was removed and excess cement was carefully removed. The specimen was stored at 37°C and 100% humidity for another 23 hours.

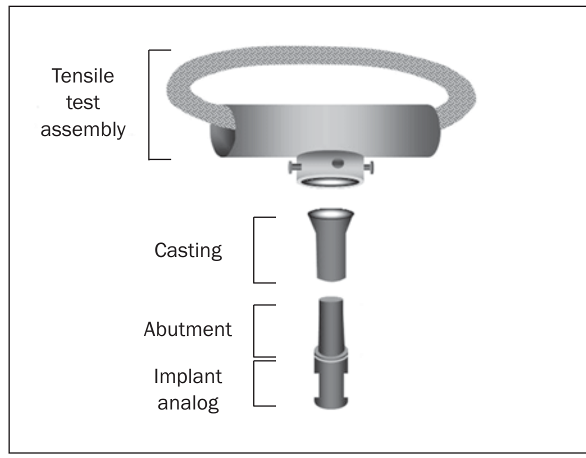

Fig 3 The test assembly was attached to the upper member of the Instron with a swivel hook. The casting was passively engaged to the test assembly with 3 set screws, and the implant analog was rigidly attached to the lower member of the Instron.

Specimens were placed into the loading machine[36] and subjected to 100,000 cycles of a compressive 75-N load at 1.2-Hz intervals. Load was applied axially with rounded stainless steel styli. The specimens were subsequently subjected to thermal cycling in distilled water baths between 5°C and 55°C with a 30-second[7,22,27] dwell time at each temperature for 1,000 cycles. Following thermal cycling, each specimen was immersed in a 0.5% aqueous solution of basic fuchsin dye for 24 hours.

Each specimen was removed from its brass mounting device and was rigidly attached to the lower member of an Instron Universal Testing Machine (Instron, Canton, MA). A 9.53-mm (3/8-inch) -diameter braided steel cable was formed into a loop and attached with a swivel hook to the upper member of the Instron. A custom-made brass fitting with 3 set screws was used to engage the casting passively with the steel cable loop (Fig 3). Uniaxial loading was applied with a 0.05 inch/min (0.125 cm/min) cross-head speed until cement failure. Subsequent to tensile bond testing, specimens were qualitatively

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Table 2 Mean Cement Failure Load (N)

Cement	n	Failure load (N)	SD	SE
RES-B-P	8	351[a]	42.4	14.9
GI	8	337[a]	35.2	12.4
ZP	8	245[b]	45.9	16.2
RES-B	8	241[b]	39.4	13.9
PCB	8	107[c]	32.4	11.4
RES	8	63[d]	21.6	7.6
UDM	8	55[d]	15.9	5.6

Statistically similar groups are denoted by superscript letters.

Table 3 Marginal Leakage Grades for Each Cement

	Grade		
Material	0	1	2
PCB	1	6	1
ZP	5	3	0
UDM	7	1	0
RES	7	1	0
GI	8	0	0
RES-B	8	0	0
RES-B-P	8	0	0

Table 4 Chi-Square Post-Hoc Values—Marginal Leakage Grade

	Grade		
Material	0	1	2
PCB	−4.919	4.257*	2.472*
ZP	−1.197	1.373	−.412
UDM	.665	−.549	−.412
RES	.665	−.549	−.412
GI	1.595	−1.510	−.412
RES-B	1.595	−1.510	−.412
RES-B-P	1.595	−1.510	−.412

*Indicates statistically significant leakage (α = .05).

examined using the unaided eye for failure mode (adhesive or cohesive) and macroscopic marginal leakage, as identified using the following criteria adapted from the method of Tjan and Chiu[29]:

- **Grade 0:** No basic fuchsin dye was seen in the internal surface of the crown (ie, no leakage)
- **Grade 1:** Leakage was confined to the lower half of the internal surface of the casting (Fig 2, area 1)
- **Grade 2:** Leakage extended beyond the lower half of the internal surface of the casting (Fig 2, area 2)

One-way ANOVA and the Scheffé post-hoc test ($\alpha = .05$) were used to categorize the effect of luting protocols on the cement failure loads. A chi-square frequency distribution was used to analyze the differences of marginal leakage values ($\alpha = .05$).

RESULTS

Mean tensile force required to separate the castings from the abutments is given by group in Table 2 and Fig 4. Statistically similar groups are noted with similar superscripts and vertical lines, respectively ($\alpha = .05$).

Results with respect to marginal leakage are given in Tables 3 and 4 and Fig 5. Seven of 8 PCB specimens demonstrated leakage; this was significantly more leakage than was seen for the other groups ($P < .01$). No significant differences were found among the remaining groups. RES-B-P, RES-B, and GI had no specimens with measurable marginal leakage. UDM and RES each had 1 specimen of grade 1. Within the ZP group, there were 3 grade-1 specimens.

The cement failure mode seen in this investigation was generally adhesive in nature, although some cohesive failure was noted. It was observed that RES-B-P and GI adhered to the abutment surface and restoration and were difficult to remove. By contrast, UDM and RES were easier to clean.

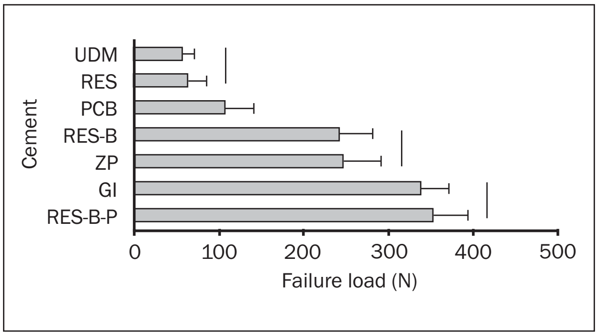

Fig 4 Mean tensile load to cement failure (N). Lines connect statistically similar groups (α = .05).

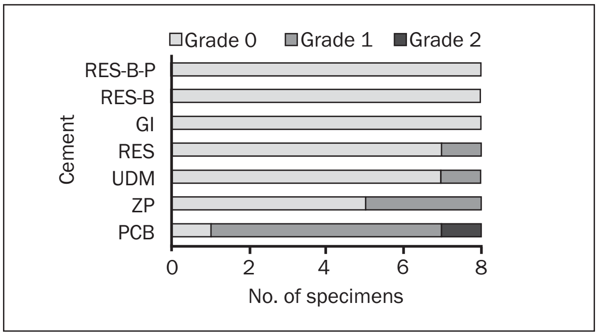

Fig 5 Marginal leakage grade for each specimen by cement tested. PCB was statistically different from the other groups ($P < .01$).

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DISCUSSION

In this in vitro study, cement failure load and marginal leakage were evaluated in single-unit castings cemented to implant abutments with 1 of 7 luting protocols using cyclic compressive loading and thermal cycling to better simulate the intraoral environment. Differences in superstructure construction, cements, cementation surface area, surface treatments, modifications to cementation protocol, and testing methodologies are a few of the variables which make comparisons between studies of this nature difficult.

This study employed 2 variables known to affect retentive properties of cements in vivo. One was repetitive compressive loading, which could cause displacement of a casting with fracture or deformation of the cement.[32,33] The other was thermal cycling, which may introduce interfacial stress due to differing coefficients of thermal expansion of the materials used.[28] The retentive properties of a cement may also be substantially affected by immersion in water or saline.[12] Since no specimens were tested prior to cyclic loading and thermal cycling, the actual effect of these experimental conditions was not ascertained in the present study.[6,7]

ZP cement has been successfully used as a luting agent for a number of years and is useful as a control in terms of comparison. With respect to relative load failure data (Table 2 and Fig 4), values for RES-B-P and GI are significantly greater than ZP and generally reflect the results of other studies.[8,9] Clinically, however, this may not be as important a distinction as other considerations such as cost, delivery system, and ease of excess cement removal. Although less leakage was seen for RES-B-P and GI when compared to ZP, other characteristics of resins and resin modified glass ionomers, such as increased water sorption and expansion over time should be considered when selecting cement.[2]

The lower failure load of the resin cement absent the adhesive primer (RES-B) was expected, because this component contains a substance that could chemically bond to the metal substrate. However, the failure load of RES-B was statistically similar to ZP, thus eliminating it from consideration as a potential provisional luting agent.

The failure load of PCB in the present study was less than half that of ZP. This result was distinctly different from that of Akca and colleagues[8]; in their study, relatively high values for 3 polycarboxylates were found in comparison to ZP.[9] This result may be partly because of the application of compressive load and thermal cycling in the present study, as well as differences in materials and mixing of the polycarboxylate materials. That significant leakage was seen with PCB in the present study is consistent with the clinical observation that this material is highly soluble in the oral cavity.[2,13,20,24] The use of PCB as a permanent or provisional implant cement is not desirable.[8]

Little data exist with respect to newer, lower-strength cements that may be selected as luting agents. Although the retentive strengths of RES and UDM were the lowest among the cements tested, there were no significant differences in the observed marginal leakage of these cements compared with the higher-strength cements, in spite of substantially different physical properties. The failure load values obtained for UDM in the present study are notably lower than some values found in the literature.[10] However, others have found values for UDM to be reduced after a period of aging.[11,12]

Among the limitations of this study are the inability to accurately simulate the intraoral environment, the specific physical conditions imposed, and correlation of artificial aging with a clinically comparable time period. Since thermal cycling and load cycling may have an additive effect, especially with resin-based cements,[14] testing both conditions concurrently would be preferred, and would better simulate the intraoral condition. The compressive forces applied were largely axially directed, as opposed to the intraoral model, in which lateral dislodging forces may be present.

In vitro leakage testing with a low-molecular-weight molecule such as basic fuchsin may be a more rigorous test than using a more clinically relevant molecule, such as one found in the oral cavity. Thus, materials exhibiting dye penetration are not likely to perform better in the oral environment.[26,30] However, as noted by Rosenstiel and associates,[2] no direct correlation has been demonstrated between marginal leakage studies and clinical performance, and results should be interpreted with caution. Additionally, it is not known what an "acceptable" level of retention is for a given clinical situation. More studies are clearly needed to better quantify various cement properties to guide clinicians in cement selection.

CONCLUSIONS

Within the limitations of this study, the following conclusions may be drawn:

1. Luting agents designated by their manufacturers as provisional cements demonstrated lower resistance to removal, regardless of material type. Luting agents described by manufacturers as permanent differed in resistance, with resin cements being most resistant, followed by zinc phosphate and polycarboxylate cements.

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2. These data do not support the use of PCB for this particular application, as PCB exhibited significantly more leakage than the other cements. The lower-strength provisional cements demonstrated leakage comparable to higher-strength materials. Although the leakage characteristics of RES-B were favorable, its failure strength indicated that it is not favorable for use as provisional cement.

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