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Retention of CAD/CAM All-Ceramic Crowns on Prefabricated Implant Abutments: An In Vitro Comparative Study of Luting Agents and Abutment Surface Area

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Keywords
CAD/CAM; dental implant abutments; dental cements; implant abutment surface area.

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The authors deny any conflicts of interest.

Accepted October 31, 2011

doi: 10.1111/j.1532-849X.2012.00847.x

Abstract

Purpose: Previous studies considering retention of cast metal restorations to implant abutments incorporated some degree of frictional fit due to internal surface nodules and roughness of the restoration. In comparison, CAD/CAM restorations have minimal surface irregularities, possibly impacting retention. There is insufficient knowledge of retentive force of CAD/CAM restorations to titanium abutments, and therefore the topic warrants further investigation. This in vitro study investigated the retention of all-ceramic CAD/CAM restorations to three different prefabricated implant abutments using five different cements.
Materials and Methods: A total of 150 Astra Tech dental implant abutments were used, with each group of 50 being subdivided into five groups of 10. An optical impression of each size of abutment was made with the CEREC 3D intraoral camera. A full-coverage restoration was designed and milled with an enlarged, conical-shaped occlusal surface, which served to secure the restoration into a brass jig used with a universal testing machine. Five different cements were used with three different-sized abutments. Following cementation, the implant/abutment/restoration assemblies were stored for 24 hours at 37°C in 100% humidity. A pull-out test using a universal testing machine, set at a 0.5 mm/min crosshead speed, was used to evaluate retention of the individual restorations. The load required to remove each all-ceramic restoration was recorded. Retention values were analyzed using ANOVA and Fisher's PLSD multiple comparisons test at the 0.05 level of significance.
Results: Peak loads for two provisional cements and a resin-modified glass ionomer cement ranged from 56 N to 127 N. Peak loads for two resin cements ranged from 184 N to 318 N. Two-way ANOVA showed significant effects upon retentive forces for both the cement and abutment design. Post hoc Fisher's PLSD multiple comparisons test found significant differences in retention for 7 of the 10 pairings of cements at a 0.05 level of significance. In addition, Fisher's PLSD multiple comparisons test found significant differences between Astra Tech Direct Abutments 4 and Astra Tech Direct Abutments 5 as well as Astra Tech Direct Abutments 4 and Astra Tech Direct Abutments 6 at a 0.05 level of significance. No significant difference was found between Astra Tech Direct Abutments 5 and Astra Tech Direct Abutments 6.
Conclusions: Of the five cements tested, the most retrievable CAD/CAM restorations were luted with Temp Bond NE and Improv Temporary Cement. Resin-modified glass

ionomer retentive forces were closer to those of the "temporary cements" than those of the permanent adhesive-resin cements. The abutment surface area became less important when using adhesive-resin cements. Retention of CAD/CAM all-ceramic restorations to prefabricated abutments has not been reported in the literature. This in vitro study demonstrated clinically significant variation among the selected cements used to retain all-ceramic CAD/CAM restorations to implant abutments. In addition, abutment size influenced the retention of all-ceramic CAD/CAM restorations.

Retention of any dental restoration to a tooth largely depends upon characteristics of the preparation, the restoration, and the cement.[1] The luting agent can vary in shear strength and thickness. The preparation and the internal surface of the restoration may vary in surface roughness and geometric configuration.[2] Preparations with nearly parallel opposing walls have greater retention than those with tapered walls; however, natural tooth preparations should be tapered for visualization, prevention of undercuts, and compensation of fabrication errors. They should also allow complete seating of the restoration during cementation.[3] As taper increases, retention decreases. A 5° convergence angle (each wall tapered 2.5°) had a retentive value of 81.3 gm/mm^2. Conversely the retentive value decreases to 41.4 gm/mm^2 with a 45° convergence angle.[4] Kaufman et al later agreed, adding that an increase in the height of the restoration also increased retention.[5] The cement bond in part is created by its mechanical interlocking between the restoration and preparation. When needed, this can be strengthened by increasing the surface area of the abutment through boxes and grooves, particularly on smaller teeth.[3]

Several distinct differences exist between natural and implant abutments. Unlike natural teeth, implant abutments are manufactured outside the mouth. It is possible to achieve more parallel walls and therefore greater restoration retention. Abutment fabrication deficiencies are not common when using modern CAD/CAM technology; however, several implant abutment characteristics are important for retention, including surface area, taper, wall height, platform size, screw access filling method, and finish of the abutment.[6,7,8]

The importance of implant abutment design was widely overlooked for many years. In the past, clinicians relied heavily on screw retention. Screw retention was originally advocated because it enabled retrievability, which allowed survival of implant components.[9] In a review of 17 studies in 1999, Goodacre et al reported screw loosening in 2% to 45% of reported cases.[10] As techniques have evolved and survival rates of implant-retained restorations have improved, the concept of retrievability has become less significant.[11] Abutment screws manufactured from gold rather than titanium have been reported to reduce the incidence of screw loosening, due to a lower coefficient of friction between the screw and abutment.[12,13]

Abutment and fixture/abutment interface design has improved drastically, incorporating a conical connection to maximize surface area contact between the implant and the abutment. This has led to less reliance on abutment screws for retention. This innovation further reduced the incidence of abutment loosening to less than 2%.[14] Cooper et al classified this design as an "interface fit" versus a "close/sliding fit" of the external and internal hex designed connections.[15] With its increased surface area and minimal micromotion, the internal conical interface between the fixture and the abutment empowered clinicians to comfortably and predictably restore single-tooth implant restorations with cement-retained restorations.[15,16]

In addition to superior occlusion and esthetics, cement-retained prostheses have a higher degree of passive fit. The cement space can compensate for minor discrepancies in the framework.[17,18] Clinicians desiring retrievable restorations may still achieve them through progressive cementation. Hebel and Gajjar advocated using increasingly stronger cements, rather than screw retention, until the desired retention is reached.[9]

The purpose of this study was to test the null hypothesis that no significant difference in retention exists for all-ceramic CAD/CAM restorations luted to three different prefabricated implant abutments using five different cements for each abutment design. The intention was to aid the clinician in developing a progressive cementation guideline for cementing CAD/CAM restorations to implant abutments.

Materials and methods

With the aid of a dental surveyor, a total of 150 implant fixture replicas were imbedded in an autopolymerizing acrylic resin block (Duralay, Reliance Dental Mfg. Co., Worth, IL) (Fig 1). Fifty of the fixtures were Astra Tech 4.0 ST, and 100 were Astra 4.5/5.0 ST. The 150 fixtures were divided into three groups of 50 for the three abutments used in this study (Table 1). Each group of 50 was subdivided into five groups of 10 for the five cements used in this study (Table 2). The abutments were torqued to 25 Ncm.

An optical impression of each size of abutment was made with the CEREC 3D (Sirona Dental Systems, Bensheim,

Figure 1 Sample implant fixture replica imbedded in autopolymerizing acrylic resin with dental surveyor.

Table 1 Implant abutments tested

Abbreviation	Abutment name	Surface area	Manufacturer
A4	Direct abutment 4	42 mm^2	Astra Tech, Mölndal Sweden
A5	Direct abutment 5	60 mm^2	Astra Tech, Mölndal Sweden
A6	Direct abutment 6	82 mm^2	Astra Tech, Mölndal Sweden

Germany) intraoral camera (Fig 2). A full-coverage restoration was designed in wax with an enlarged, conical-shaped occlusal surface, which served to secure the restoration into a brass jig to be used with a universal testing machine (Instron Corp., Canton, MA) (Fig 3). Using the CEREC 3D correlation design software, 50 ceramic duplicates of the wax-up were manufactured for each abutment size. Parameter settings included margin thickness, adhesive gap, and spacer set to 0 μm. (Note that when the system parameter of spacer is set to 0 μm it actually defaults to 100 μm.)

In all, 10 CEREC 3D units were used to mill the specimens. The two burs used in each unit were the 1.6-mm cylinder diamond and the 1.6-mm cone-shaped cylinder diamond. Each restoration was catalogued by abutment size, machine number, ceramic reference, and lot number, as well as how many times each bur was used. Burs were changed after five millings, to control any variability in bur wear.

ProCad (Ivoclar Vivadent, Schaan, Liechtenstein) porcelain milling blocks were used to fabricate the restorations. Following milling, the intaglio surfaces of the crowns were cleaned using air abrasion. Implant abutments were cleaned with alcohol prior to cementation. Cements were mixed according to the manufacturer's recommendations, and the specimens were seated with finger pressure onto their respective abutments. Excess cement was removed with a plastic scaler. The all-ceramic restorations were then loaded on their long axis with a 2 kg weight. This variation from ADA specification #96, which calls for a load of 5 kg, was done because pilot studies revealed ceramic fracture along the margin of the implant abutments when loaded with weight greater than 2 kg. This was particularly evident with smaller abutments (Fig 4). Mixing and cementing procedures were carried out at room temperature by one investigator.

Following cementation, the implant/abutment/restoration assemblies were stored for 24 hours at 37°C in 100% humidity. A pull-out test using a universal testing machine (Instron) set at a 0.5 mm/min crosshead speed was used to evaluate retention of the individual restorations. The load required to remove each all-ceramic restoration was recorded. Failure was at the abutment/restoration interface, not within the ceramic. An adhesive remnant index was compiled to analyze failure of the abutment/restoration interface.

The null hypothesis was that no differences existed in the retentive strength of the five cements, and no differences existed in retention among the three different-sized Ti abutments. Retention values were analyzed using ANOVA and Fisher's PLSD

Table 2 Cements tested

Abbreviation	Cement name	Cement type	Manufacturer
TBNE	Temp Bond NE	Oil-based provisional luting cement	Kerr Corporation, Orange, CA
IP	ImProv	Acrylic/urethane provisional cement	Nobel Biocare, Göteborg Sweden
RLP	3M ESPE Rely X Luting Plus	Resin-modified glass ionomer cement	3M ESPE, St. Paul, MN
ML	3M ESPE Rely X Unicem Self Adhesive Universal Resin Cement	Self-adhesive resin cement	3M ESPE, St. Paul, MN
RUC	Multilink	Self-adhesive resin cement	Ivoclar Vivadent, Amherst, NY

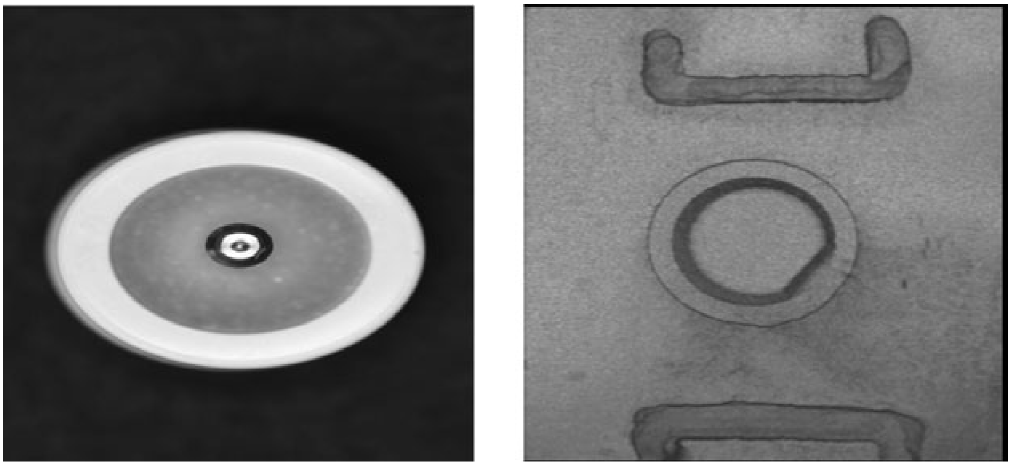

Figure 2 Optical impression of Direct 6 abutment.

Figure 3 Sample of a full-coverage ceramic test restoration fabricated using the CEREC 3D system. The occlusal surface has been modified to fit the securing jig of the instron machine.

multiple comparisons test (StatView, SAS Institute, Cary, NC) at the 0.05 level of significance.

Results

Peak load means and standard deviations of retention of restorations to abutments are listed in Table 3. Peak loads for two provisional cements and a resin-modified glass ionomer cement ranged from 56 N to 127 N. Peak loads for two resin cements ranged from 184 N to 318 N. Two-way ANOVA (Table 4) for retentive force showed significant main effects for the cement factor and significant main effects for the implant factor. Post hoc Fisher's PLSD multiple comparisons test, at a 0.05 level of significance, found significant differences for 7 of 10 pairings

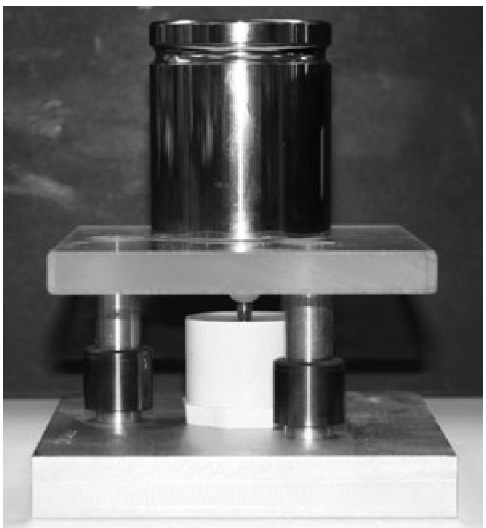

Figure 4 Crown seating device. All-ceramic restorations were loaded on their long axis with 2 kg weight.

Table 3 Means (sd) for peak load (N)

		Implant abutments		
		A4	A5	A6
Cements	TBNE	83 (20)	82 (21)	114 (38)
	IP	92 (69)	127 (29)	104 (26)
	RLP	96 (23)	84 (60)	56 (29)
	ML	199 (24)	241(51)	246 (58)
	RUC	184 (56)	237 (35)	318 (54)

of cements (Table 5). The exceptions were Multilink and Rely-X Unicem, Temp Bond NE and Improv, and Temp Bond NE and Rely-X Luting Plus. In addition, Fisher's PLSD multiple comparisons test, at a 0.05 level of significance, found significant differences between Astra Tech Direct Abutments 4 and Astra Tech Direct Abutments 5 and between Astra Tech Direct Abutments 4 and Astra Tech Direct Abutments 6. No significant difference was found between Astra Tech Direct Abutments 5 and Astra Tech Direct Abutments 6 (Table 6).

Discussion

This study focused on cement-retained implant restorations. It was not intended to designate a superior cement, but rather give clinicians a spectrum of possibilities when cementing implant restorations.[19,20] The selected cements, while limited in number, provide the clinician a spectrum of possibilities that may be used to achieve desired retention.

Retention of full coverage dental restorations to natural abutments involves numerous variables including convergence angle, axial wall height and diameter, surface area, margin geometry, and any additional retentive features incorporated by the clinician.[21] Also important is the surface finish of both the preparation and the restoration, the physical properties of the cement, placement technique, seating force, and environmental conditions during delivery.[4,21,22] While many of these features are held in common with implant dentistry, significant differences exist between smooth, machined abutments, and natural teeth.[19] The surface irregularities of natural teeth do not exist on manufactured smooth abutments.

Kaufman et al, in a study on the retention of gold castings, described the "uncemented grip" of a full-coverage restoration.[23] Others have referred to it as the "frictional fit" of the cast crown restoration.[24] Regardless of the name, this phenomenon can be attributed to "unavoidable discrepancies" in the manufacturing process, including internal surface nodules and roughness of the restorations.[25] In a study of fixed partial denture retainers, Lorey and Myers found no relationship between precementation and postcementation retention values, a conclusion also found in other investigations.[26,27] Lorey and Myers theorized that tight castings reduce the thickness of cement below optimal levels, ultimately reducing retention. This suggested that a well-fitting casting should seat easily and provide a uniform cement space.[26] Grajower et al added that tight castings could result in damage or "digging" into natural abutments, resulting in increased crown elevation.[28]

Table 4 Two-way ANOVA for peak load (kN)

	DF	Sum of squares	Mean square	F-value	*p*-value	Lambda	Power
Cement	4	0.772	0.193	105.256	<0.0001	421.025	1.000
Implant	2	0.034	0.017	9.362	0.0002	18.724	0.985
Cement * Implant	8	0.090	0.011	6.168	<.0001	49.341	1.000
Residual	135	0.247	0.002				

Table 5 Fisher's PLSD for peak load (kN) significance level: 5%, effect: cement

	Mean difference	Crit. Diff	*p*-value
TBNE, IP	−0.013	0.022	0.2417
TBNE, RLP	0.015	0.022	0.1859
TBNE, ML	−0.136	0.022	<0.0001
TBNE, RUC	−0.153	0.022	<0.0001
IP, RLP	0.028	0.022	0.0134
IP, ML	−0.123	0.022	<0.0001
IP, RUC	−0.140	0.022	<0.0001
RLP, ML	−0.150	0.022	<0.0001
RLP, RUC	−0.168	0.022	<0.0001
ML, RUC	−0.017	0.022	0.1207

CAD/CAM systems do have flaws, and manufacturing discrepancies do exist on the internal surface of the restoration; however, they are minimal compared to hand-fabricated restorations, and should not be expected to have a significant effect on retention. Retention is more dependent on the properties of the abutment (natural or titanium) and the cement. Mansour et al have already noted in a previous study that cements should be expected to react differently with implant abutments than with natural abutments.[19] This study was unique in that it was one of the first to consider CAD/CAM crowns on machined abutments. Each abutment and crown combination was only tested once. Specimens were not reused because previous studies considered this to be a possible source of error. Inadvertent damage to the abutments occurring during the cleaning process, introducing some new mechanical interlocking between the crown and abutment, did not occur.

Many specimens in this study demonstrated a lack of parity in retentive strength between the adhesive-resin cements and the nonadhesive-resin cements. Restorations cemented with Rely-X Unicem Self Adhesive Resin Cement to the Direct Abutment 6 showed the highest overall retention values. Both of the adhesive-resin cements significantly outperformed the provisional cements and the resin-modified glass ionomer cements, which depend more on mechanical retention. Rely-X Luting Plus, a resin-modified glass ionomer, had retentive forces closer to the "temporary cements" than to the permanent adhesive-resin cements. A possible explanation is that the strength of glass ionomer cements increases over time. This may be a limitation of this study since all specimens were tested at 24 hours postcementation.[29] Further evaluation of glass ionomer cements is needed.

Table 6 Fisher's PLSD for peak load (kN) significance level: 5%, effect: implant

	Mean difference	Crit. diff	*p*-value
A4, A5	−0.023	0.017	0.0095
A4, A6	−0.037	0.017	<0.0001
A5, A6	−0.014	0.017	0.0996

The Direct Abutment 4, with a surface area of 42 mm^2, was significantly less retentive than Direct Abutment 5, which had a surface area of 60 mm^2 and Direct Abutment 6, which had a surface area of 82 mm^2.[30] The adhesive-resin cements, Multilink and Rely-X Unicem, were not significantly different in retention according to Fisher's PLSD multiple comparisons test. Since they constituted 40% of the selected cements, this probably helped to bring the retention of Direct Abutment 5 and Direct Abutment 6 closer together. Selection of different cements would probably influence outcomes and possibly demonstrate greater differences between Direct Abutment 5 and Direct Abutment 6.

Conclusions

Within the limitations of this in vitro study, the following was concluded:

1. Of the five cements tested, Temp Bond NE and Improv Temporary Cement allowed the most retrievability.
2. The retentive force of restorations cemented with resin-modified glass ionomer was closer to that of the "temporary cements" than that of permanent adhesive-resin cements.
3. Although abutment surface area is important, its importance decreased when adhesive-resin cements were used.

Acknowledgments

The authors would like to recognize Astra Tech and Ivoclar Vivadent for their invaluable material support toward this project.

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