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Original Research

Effect of Cement Type and Surface Modifications on Retention and Titanium Surface Stability in Implant Crowns

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ABSTRACT

Objective: The aim of this study was to evaluate the effects of different cement types and surface treatments on retention, to assess the impact of mechanical loading and thermocycling on retention, and to examine the resulting surface alterations.

Methods: A total of 120 abutment analogs were prepared for full metal crowns. A total of 40 crowns were randomly cemented with four cements without surface treatment and tested for retention. Selected specimens were examined using scanning electron microscopy (SEM). All specimens underwent mechanical loading and thermal cycling, followed by retention testing and SEM analysis. In the experimental groups, internal crown surfaces were sandblasted or diamond-burr roughened prior to aging and retention testing. Retention data were analyzed using one-way ANOVA and Tukey's honestly significant difference (HSD) tests ($\alpha = 0.05$).

Results: Permanent cements showed significantly higher retention than temporary cements across all treatments, with no differences within cement groups. Surface treatment did not significantly affect retention, and no statistically significant differences were observed between non-aged and aged specimens under the applied aging protocol. SEM revealed no observable morphological changes on the titanium surfaces before and after aging. Predominantly adhesive failures were observed, whereas both adhesive and cohesive failures were observed for Panavia SA. Air bubbles were present in manually mixed cements but absent in automix-prepared cements.

Conclusion: Cement type significantly affects retention of implant-supported crowns. Aging and crown surface roughening do not significantly influence retention, and no chemical changes were observed on titanium surfaces.

Keywords: ANOVA, computer-aided design and computer-aided manufacturing, dental cements, dental crowns, prostheses and implants, scanning electron microscopy

INTRODUCTION

The retention of implant-supported fixed prostheses can be achieved using either screw- or cement-retained designs. Although no consensus has been reached regarding the superiority of one retention method over the other, cement-retained restorations are often preferred because of their lower complication rates and greater fracture resistance in ceramic superstructures. In addition, cement retention offers several clinical advantages, including passive seating of the restoration, preservation of occlusal surface integrity, simplified fabrication procedures, and reduced treatment costs [1–6]. Nevertheless, the retrievability of cement-retained implant restorations remains a clinical concern. Removal of implant-supported prostheses may be required for routine maintenance, management of screw loosening or fracture, abutment failure, prosthetic modifications following implant loss, or evaluation of peri-implant tissues and oral hygiene conditions [6,7].

Luting agents used for implant-supported prostheses are broadly classified as permanent or temporary cements. Among permanent cements, zinc phosphate, zinc polycarboxylate, glass ionomer, and self-curing resin cements have been extensively utilized and are frequently considered benchmark materials in comparative studies assessing retentive strength [8,9]. To facilitate the retrieval of cement-retained implant prostheses when necessary, some authors have advocated the use of temporary cements as an alternative to permanent luting agents. Temporary cements may allow prosthesis removal with a lower risk of damage to the restoration, implant components, or surrounding peri-implant tissues [10,11]. Zinc oxide-eugenol cements offer the advantage of facilitating the retrieval of restorations; however, their low tensile strength and poor physical properties resulting from high solubility may compromise restoration retention and lead to patient dissatisfaction [12]. As a result, increasing attention has been directed toward resin-based semipermanent cements, which aim to combine sufficient retentive strength with the ability to retrieve the prosthesis when necessary [13].

Main Points

- The type of cement significantly affects the retention of implant-supported fixed prostheses.
- Aging procedures do not have a significant effect on cement retention.
- Surface roughening of the internal crown surfaces does not significantly influence retention values.
- The cements tested did not induce any physical or chemical alterations on the titanium surface, and no chemical bonding to titanium was observed.

Several techniques have been proposed to improve the retention of cement-retained implant restorations, including increasing the surface area, ensuring parallelism of opposing surfaces, controlling the preparation taper [14,15] and incorporating retentive grooves [16–18]. In addition, increasing surface roughness has been shown to enhance the mechanical retention of the cement [19,20]. Surface roughening of both the abutment and the internal surface of the prosthesis using diamond burs has also been reported to increase retention [21]. Various surface modification methods are employed to improve cement adhesion to restorative surfaces, which include acid etching, aluminum oxide air abrasion, diamond bur roughening, laser surface treatment, and combinations of these techniques [22].

In vitro studies allow the simulation of selected oral environmental factors and provide an approximation of the clinical performance of dental materials. Thermal cycling, one of the most commonly used artificial aging methods, subjects specimens to repeated temperature fluctuations that simulate intraoral thermal changes and may affect the physical and mechanical properties of materials [23,24]. In addition, compressive cyclic loading is widely employed to reproduce occlusal forces and assess the retention performance and durability of dental cements under functional conditions [25,26].

Cement selection is considered one of the most important factors influencing the retention of cement-retained implant restorations [27,28]. Various luting agents have been proposed for the cementation of implant-supported prostheses, each exhibiting different retentive properties. However, the effect of cement type on the retention of implant-supported restorations remains controversial. Previous studies have reported varying results regarding the retentive performance of different cements, which may be related to differences in study designs, testing protocols, abutment characteristics, and aging procedures [17,23,26,29,30].

The aim of this study was to compare the retention of laser-sintered metal crowns cemented with four different luting cements and two surface treatment protocols on solid titanium abutment analogs, and to evaluate the effect of thermal aging on retention in the absence of surface treatment. The null

hypothesis was that cement type, surface treatment, and thermal aging would not significantly affect retention values.

MATERIALS AND METHODS

A total of 120 models were prepared using solid abutment analogs (Evoss Implant, SC Medical) measuring 5 mm in length and 4.8 mm in diameter. The abutment analogs were embedded in polymethyl methacrylate (PMMA)-based acrylic resin (SC Acrylic, Imicryl) using the molds of a chewing simulator device (CS-4.8 Chewing Simulator, SD Mechatronik).

A parallelometer (Paraskop M, Bego) and a micromotor (Strong 210, Saeshin Precision) were used to ensure proper parallelism during analog placement. The parallel alignment of the parallelometer table with the ground was verified using a spirit level. One specimen was randomly selected and digitized using a 3D scanner (Iseries, Dental Wings). Full-coverage metal crowns were designed on the digital model using CAD software (DWOS, Dental Wings).

The cement space was set to 0.20 µm, and a 1/30 ratio was selected for the tightest cervical fit, ensuring optimal marginal adaptation and minimal marginal gap. The finish line was defined as a shoulder finish line. Ring-shaped retainers were attached to the occlusal surfaces of the metal crowns to enable tensile testing for retention measurement (Figure 1).

The standard-designed crowns were fabricated from a cobalt-chromium alloy recommended by the manufacturer for this system, using a selective laser sintering machine (M Cusing Lab; Concept Laser GmbH). No modifications were made to the internal surfaces of the crowns; only the external surfaces were finished. The fit of the metal crowns was visually assessed by a single operator for each specimen.

After inspection, the crowns were cleaned using a steam cleaner (Vap 6 Steam Cleaner, Zhermack) and subsequently ultrasonically cleaned in 99.8% isopropanol (2-propanol,

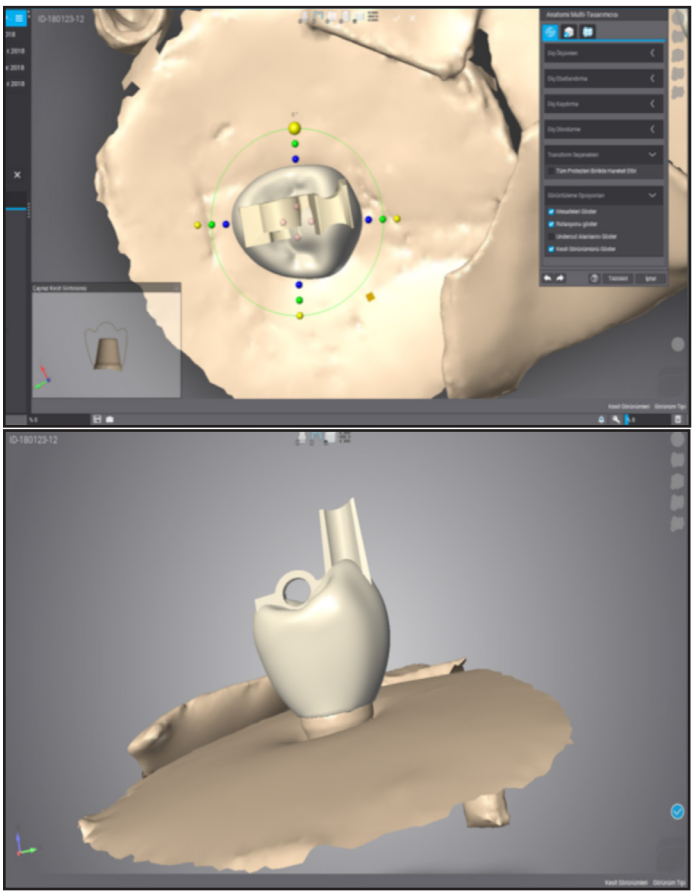

Figure 1. Crown design. A, Computer-Aided Crown Design B, Side view of ring-shaped retainer

Emsure) for 10 minutes at 40°C using an ultrasonic bath (Elmasonic S, Elma).

For the control group, 40 models were randomly selected and divided into four subgroups of 10 specimens according to four different cement types (Table 1). No surface treatment was applied to the internal surfaces of the metal crowns. Cementation was performed by a single operator in accordance with the manufacturers' instructions: finger pressure was applied for 2 minutes, followed by controlled setting at room temperature for 10 minutes. After removal of excess cement, the specimens were stored at room temperature for 24 hours to allow complete polymerization.

Table 1. Properties of the cements used

Name of cement	Type of cement	Content of cement	Manufacturer
Temp-Bond	Temporary	Zinc oxide Eugenol	Kerr Dental
Dentotemp	Temporary	Zinc oxide Non-eugenol Resin/polymer matrix	Itena
Adhesor Carbofine	Permanent	Zinc polycarboxylate	Pentron
Panavia SA Cement Plus	Permanent	Resin cement containing LCSi monomer	Kuraray

Retention was measured for all specimens using a universal testing machine (Instron 3,345, Instron), applying a metal hook specifically designed to engage the rings on the occlusal surfaces of the metal crowns at a crosshead speed of 0.5 mm/min.

For each cement type, two abutments and two metal crowns were randomly selected for scanning electron microscopy (SEM) analysis to evaluate the effects of the cements on the titanium surface. SEM examinations were performed using a scanning electron microscope (Zeiss EVO LS 10; Carl Zeiss Microscopy GmbH) at magnifications of 46–51× and 500× for abutments, and 35× and 125–250× for metal crowns. Based on the SEM findings, specimens from the control group were also included as a subgroup in the e×perimental group and subjected to the aging protocol without any surface treatment.

Following SEM analyses in the control group, all metal crowns were cleaned of residual cement using only steam and ultrasonic cleaning. Because residual cement on the inner surfaces of crowns cemented only with Panavia SA could not be removed without mechanical processing, 10 new metal crowns were fabricated for this cement group. After cementation with four different cements without any surface treatment, the samples were aged in a chewing simulator and thermal cycling device, and then a second retention measurement was performed. Two randomly selected abutments and their metal crowns were subjected to SEM analysis once more. Analysis was performed at 46–51 × and 500 × magnifications for the abutments, and 35× and 125–250 × magnifications for the cement on the inner surfaces of the metal crowns.

In the sandblasting group (n = 40), the internal surfaces of the metal crowns were treated with 110 µm Al_2O_3 particles under 2.5 atm air pressure, from a distance of approximately 3 mm for 20 seconds. All sandblasting procedures were performed by a single operator to ensure uniform application across all specimens.

In the diamond bur group (n = 40), the internal surfaces of the metal crowns were roughened by a single operator using a rotary instrument operating at 20,000 rpm for 30 seconds. A new diamond bur was used for each crown to standardize the roughening procedure.

Cementation for each cement type was performed by a single operator according to the manufacturers' instructions. Finger pressure was applied for 2 minutes, followed by controlled setting at room temperature for 10 minutes. After removal of excess cement, the specimens were stored at room temperature for 24 hours to allow complete setting reactions.

The force applied in the chewing simulator and thermocycling device (CS-4.8, SD Mechatronik) was set at 100 N. The crowns were aligned so that the buccal cusps were positioned parallel to the long axes of the metal antagonists. Metal balls were used as antagonists. Mechanical aging consisted of 100,000 chewing cycles combined with thermocycling between 5°C and 55 °C Based on previous reports indicating 800–1,400 chewing cycles per day and 10,000 cycles corresponding to approximately 1–2 weeks of clinical use, 100,000 cycles were considered to simulate approximately six months of clinical service [31]. This protocol was designed to evaluate the early effects of mechanical and thermal aging on retention, as changes at the cement-restoration interface and loss of retention may occur during the initial period of clinical function.

Retention measurements for all specimens were performed using a universal testing machine (Instron 3,345, Instron). A metal hook adapted to engage the rings on the occlusal surfaces of the metal crowns was used, and tensile force was applied at a crosshead speed of 0.5 mm/min. The maximum dislodgement force was recorded in Newtons (N).

Statistical Analysis

Data were analyzed using statistical software (IBM SPSS Statistics for Windows, v22.0; IBM Corp). The statistical approach was based on the predefined experimental comparisons and the specific objectives of the study. The primary objective was to evaluate differences in retention among the four cement types within each experimental condition. Therefore, one-way analysis of variance (ANOVA) followed by Tukey HSD post hoc comparisons was used to assess differences among cement types within the control and each surface-treatment condition. The effect of surface treatment was evaluated separately for each cement type using one-way ANOVA. The effect of aging in the untreated condition was evaluated by comparing independent groups of non-aged and aged specimens using independent-samples t-tests. The normality of data distribution was assessed using the Kolmogorov-Smirnov test. A significance level of $\alpha = 0.050$ was used for all analyses. Because the analyses were designed to address the predefined group-wise comparisons, potential interaction effects among cement type, surface treatment, and aging were not formally assessed.

RESULTS

The means and standard deviations of the retention values for all groups are presented in Table 2. The normality of the data in the control group was assessed using the Kolmogorov-Smirnov test, which confirmed a normal distribution across cement types ($p > 0.050$). One-way ANOVA was performed to evaluate differences in retention values among the four cement types within the control group. A statistically significant difference was observed ($p < 0.010$).

Post-hoc pairwise comparisons were conducted using the Tukey HSD test. The results revealed a statistically significant difference between permanent cements (Adhesor Carbofine and Panavia SA) and temporary cements (Temp-Bond and Dentotemp) ($p < 0.010$). No statistically significant difference was found between the two temporary cements ($p = 0.982$), nor between the two permanent cements ($p = 0.123$).

In each surface-treatment condition (no surface treatment, sandblasted, and diamond bur-roughened), normality of the data was confirmed using the Kolmogorov-Smirnov test ($p > 0.050$). One-way ANOVA was used to evaluate differences in retention values among the four cement types within each surface-treatment condition. A statistically significant difference in retention values was observed among cement types ($p < 0.010$). Post-hoc pairwise comparisons were performed using the Tukey HSD test.

In the no surface treatment group, a statistically significant difference was found between permanent cements (Adhesor Carbofine and Panavia SA) and temporary cements (Temp-Bond and Dentotemp) ($p < 0.010$). No significant differences were observed between the two temporary cements ($p > 0.050$) or between the two permanent cements ($p > 0.050$).

In the sandblasted group, a statistically significant difference was again observed between permanent and temporary cements ($p < 0.010$). No significant differences were found between Temp-Bond and Dentotemp ($p = 0.998$), or between Adhesor Carbofine and Panavia SA ($p = 0.053$).

In the diamond bur-roughened group, a statistically significant difference was also observed between permanent and temporary cements ($p < 0.010$). No significant differences were found between Temp-Bond and Dentotemp ($p = 0.988$), or between Adhesor Carbofine and Panavia SA ($p = 0.917$) (Table 3,4).

Table 2. Retention values (N) of all groups

Group	Aging	Subgroup (Cements)	Retention values Mean ±SD (N)
Group without surface treatment	No	Adhesor Carbofine	255.0 ±76.9
		Panavia SA	311.6 ±70.4
		TempBond	52.0 ±28
		Dentotemp	61.3 ±26.1
Group without surface treatment	Yes	Adhesor Carbofine	212.9 ±84.7
		Panavia SA	322.9 ±55.6
		TempBond	49.5 ±40.8
		Dentotemp	72.6 ±28.7
Roughened group by sandblasting	Yes	Adhesor Carbofine	183.2 ±72.4
		Panavia SA	247.1 ±52.3
		TempBond	66.9 ±32.6
		Dentotemp	63 ±26.7
Roughened group with diamond bur	Yes	Adhesor Carbofine	245.8 ±57.5
		Panavia SA	224.1 ±127.0
		TempBond	61 ±31.7
		Dentotemp	71.9 ±47.4

SD. Standard deviation

Table 3. One-way ANOVA results of the surface treatment groups

Surface Treatment		Sum of Squares	*df*	Mean Square	F	p
Roughened group by sandblasting	Between Groups	246092.500	3	82030.833	28.621	0.000*
	Within Groups	103181.400	36	2866.150		
	Total	349273.900	39			
Roughened group with diamond bur	Between Groups	286792.219	3	95597.406	16.838	0.000*
	Within Groups	204384.725	36	5677.353		
	Total	491176.944	39			

*Statistical significance ($p < 0.050$)

Table 4. Results of Tukey post hoc multiple pairwise comparison test for surface treatments among groups tested

Surface Treatment	Group		Adhesor Carbofine	Panavia SA	TempBond	Dentotemp
Roughened group by sandblasting	Adhesor Carbofine	Mean difference	-	-63.90000	116.30000	120.20000
		p	-	0.053	0.000*	0.000*
	Panavia SA	Mean difference	-	-	180.20000	184.10000
		p	-	-	0.000*	0.000*
	TempBond	Mean difference	-	-	-	3.90000
		p	-	-	-	0.998
	Dentotemp	Mean difference	-	-	-	-
		p	-	-	-	-
Roughened group with diamond bur	Adhesor Carbofine	Mean difference	-	21.70000	184.80000	173.85000
		p	-	0.917	0.000*	0.000*
	Panavia SA	Mean difference	-	-	163.10000	152.15000
		p	-	-	0.000*	0.000*
	TempBond	Mean difference	-	-	-	-10.95000
		p	-	-	-	0.988
	Dentotemp	Mean difference	-	-	-	-
		p	-	-	-	-

* Groups significantly different ($p < 0.050$)

One-way ANOVA was performed separately for each cement type to evaluate the effect of surface treatment on retention values. The results indicated that surface treatment had no statistically significant effect on retention values for any of the cement types ($p > 0.050$) (Table 5).

To assess the effect of aging on retention in the no-surface-treatment condition, independent-samples t-tests were conducted separately for each cement type by comparing the non-aged and aged specimens. No statistically significant differences were found between the non-aged and aged groups for any of the cement types ($p > 0.050$) (Table 6).

SEM analysis of specimens from the no surface treatment group before (Figure 2) and after aging (Figure 3) revealed no observable morphological changes on the titanium abutment surfaces. Predominantly adhesive failures were observed at the cement-metal crown interface. In addition, both adhesive and cohesive failures were observed in Panavia SA cement. Air voids were detected in manually mixed cements such as Adhesor Carbofine and Temp-Bond, whereas no voids were observed in materials mixed using an automix system.

Table 5. One-Way ANOVA of Surface Treatment Effects on Retention Values for Different Cement Types

Types of Cement		Sum of Squares	*df*	Mean Square	F	p
Adhesor Carbofine	Between Groups	19610.867	2	9805.433	2.517	0.099
	Within Groups	105192.100	27	3896.004		
	Total	124802.967	29			
Panavia SA	Between Groups	53453.600	2	26726.800	2.933	0.070
	Within Groups	246058.700	27	9113.285		
	Total	299512.300	29			
TempBond	Between Groups	1566.067	2	783.033	0.621	0.545
	Within Groups	34057.400	27	1261.385		
	Total	35623.467	29			
Dentotemp	Between Groups	575.617	2	287.808	0.209	0.812
	Within Groups	37106.625	27	1374.319		
	Total	37682.242	29			

Table 6. The effect of aging on retention values

Cement type		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	99% Confidence Interval of the Difference	
									Lower	Upper
Adhesor Carbofine	Equal variances assumed	0.448	0.512	1.166	18	0.259	42.20000	36.20064	-33.85473	118.25473
	Equal variances not assumed			1.166	17.836	0.259	42.20000	36.20064	-33.90496	118.30496
Panavia SA	Equal variances assumed	0.387	0.542	-0.398	18	0.695	-11.30000	28.38061	-70.92544	48.32544
	Equal variances not assumed			-0.398	17.080	0.695	-11.30000	28.38061	-71.15641	48.55641
TempBond	Equal variances assumed	0.996	0.332	0.160	18	0.875	2.50000	15.64484	-30.36860	35.36860
	Equal variances not assumed			0.160	15.941	0.875	2.50000	15.64484	-30.67553	35.67553
Dentotemp	Equal variances assumed	0.142	0.711	-0.921	18	0.369	-11.30000	12.26671	-37.07141	14.47141
	Equal variances not assumed			-0.921	17.841	0.369	-11.30000	12.26671	-37.08787	14.48787

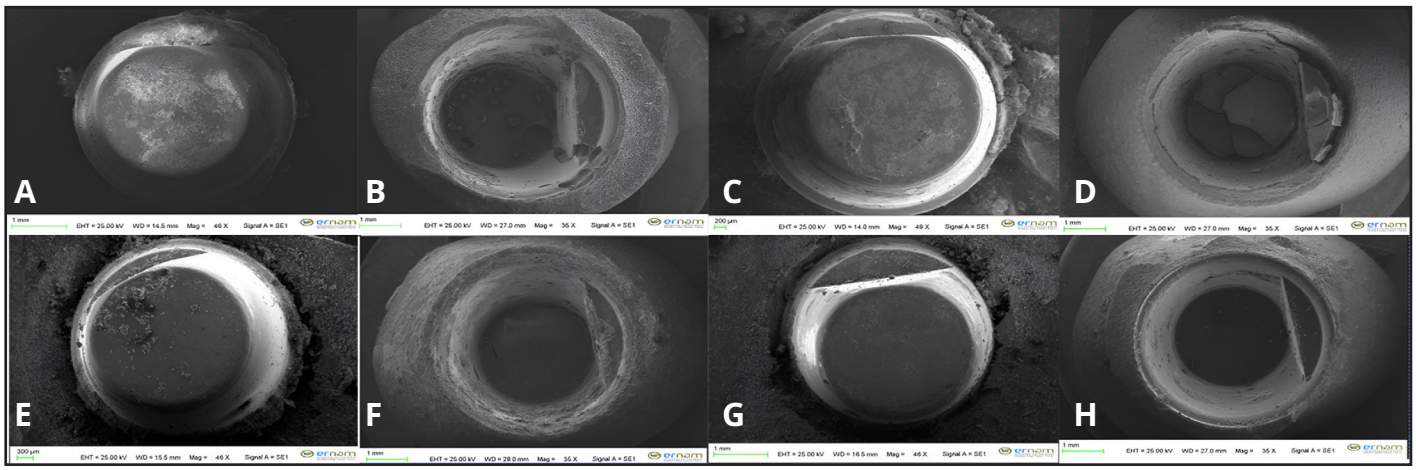

Figure 2. Scanning electron microscope images of the abutment surface and inner crown surfaces after retention value measurement of samples without surface treatment and thermal aging for 4 different cement types. A, Abutment surface cemented with Adhesor Carbofine cement. B, Inner surface of the crown cemented with Adhesor Carbofine cement.C, Abutment surface cemented with Panavia SA cement. D, Inner surface of the crown cemented with Panavia SA cement. E, Abutment surface cemented with Temp-Bond cement. F, Inner surface of the crown cemented with Temp-Bond cement. G, Abutment surface cemented with Dentotemp cement. H, Inner surface of the crown cemented with Dentotemp cement.

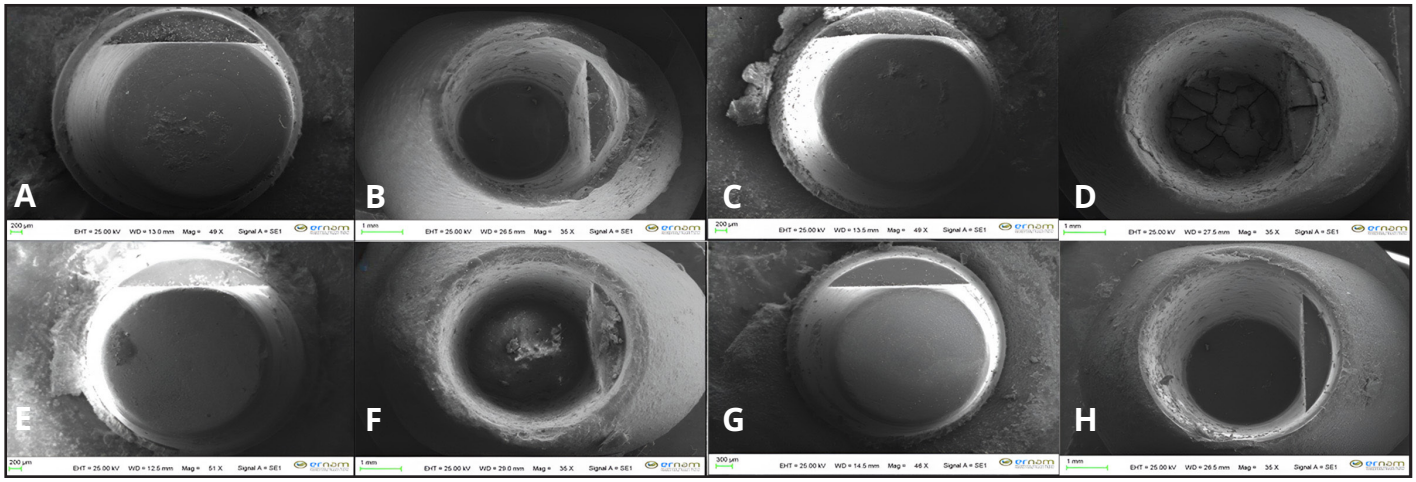

Figure 3. Scanning electron microscope images of the abutment surface and crown inner surfaces after retention value measurement of samples that were not surface treated but were thermally aged for 4 different cement types. A, Abutment surface cemented with Adhesor Carbofine cement. B, Inner surface of the crown cemented with Adhesor Carbofine cement.C, Abutment surface cemented with Panavia SA cement. D, Inner surface of the crown cemented with Panavia SA cement. E, Abutment surface cemented with Temp-Bond cement. F, Inner surface of the crown cemented with Temp-Bond cement. G, Abutment surface cemented with Dentotemp cement. H, Inner surface of the crown cemented with Dentotemp cement.

DISCUSSION

The retention of implant-supported restorations is influenced by multiple factors, including the physical and mechanical properties of the metal substructure, as well as the type, composition, viscosity, and film thickness of the luting agent [25,32]. In addition, the geometric characteristics of the implant abutment, such as convergence angle, diameter, height, surface area, and surface roughness, play a significant role in retention [15,16,32]. Despite numerous studies and different clinical protocols, the selection of an optimal cement for implant-supported prostheses remains controversial [7,23,32]. Cement type has been reported as one of the most critical factors affecting the retention of these restorations [9,27,32].

In light of these considerations, the present study tested the null hypothesis that cement type, surface treatment, and aging would have no significant effect on the retention values of implant-supported restorations. The findings of the present study partially rejected this hypothesis, as cement type significantly influenced retention, whereas surface treatment and aging did not demonstrate a statistically significant effect.

The retention of cemented implant-supported restorations is influenced by the interaction between the luting agent and the titanium abutment surface. In contrast to natural teeth, titanium abutments do not exhibit caries or intrinsic surface irregularities, which may result in a lower bonding potential compared to enamel and dentin substrates [35]. For this reason, achieving adequate retention in implant-supported restorations depends largely on the properties of the luting cement [19,21].

In this context, cement selection becomes a critical factor in clinical practice. In the present study, one conventional polycarboxylate-based permanent cement, one resin-based permanent cement, and two eugenol-free temporary cements were selected, as these materials are commonly used in implant prosthodontics and represent different retention mechanisms and clinical indications.

The present findings demonstrated that cement type had a significant effect on retention, supporting the importance of luting agent selection. This result is consistent with previous studies reporting that resin-based cements generally provide higher retention compared to conventional temporary or polycarboxylate-based cements.

The results demonstrated that cement type had a significant effect on retention, highlighting its importance in cement selection. This finding is consistent with previous studies reporting higher retention values for resin-based cements compared with conventional and temporary luting agents [9,13,14,37]. However, the absence of a universally accepted minimum retention threshold for implant-supported restorations continues to generate controversy in cement selection. While some authors advocate the use of temporary cements to facilitate retrievability and reduce the risk of peri-implant complications [7,11], others recommend permanent resin-based cements to ensure long-term stability and retention [36].

Within this framework, each cement category demonstrated distinct retention characteristics and mechanical behavior. Resin-based cements have consistently been reported to provide the highest retention values due to their superior mechanical properties, adhesive potential, and resistance to oral fluid degradation. Studies have shown that resin cements such as Panavia and Multilink Implant achieve significantly higher retention compared with conventional and provisional cements, particularly in situations requiring long-term stability [9,28,37]. In the present study, Panavia SA also demonstrated high retention performance, supporting the findings of previous investigations.

Conventional permanent cements, including zinc phosphate, glass ionomer, and polycarboxylate-based materials, have also been reported to provide measurable retention in implant-supported restorations [27,38]. Although their bonding mechanism is primarily based on micromechanical interlocking rather than chemical adhesion, their retention performance has been investigated under various experimental conditions. In the present study, Adhesor Carbofine exhibited relatively high retention values, consistent with the retention performance reported for conventional permanent cements in previous studies.

In contrast, temporary cements, particularly zinc oxide eugenol-free formulations, generally provide lower retention, which facilitates retrievability but may increase the risk of debonding under functional loading [10,39,40]. Sarfaraz et al. [38] and Hendi et al. [39] also reported lower retention values for temporary cements such as Temp-Bond and Dentotemp, which is in agreement with the present findings. Although minor differences among temporary cements have been reported, their overall retention capacity remains significantly lower than that of permanent cements.

Implant-specific luting agents have been developed to balance retention and retrievability; however, their performance remains variable across studies, suggesting that their clinical behavior is highly dependent on cement composition and experimental conditions [23,32].

Overall, the present findings indicate that cement type is the primary determinant of retention, with permanent cements providing significantly higher retention than temporary cements. These results align with the majority of existing literature and

reinforce the importance of luting agent selection in achieving an optimal balance between retention and retrievability in implant-supported prostheses.

Surface roughening techniques applied to implant components have been widely reported to enhance retention by increasing micromechanical interlocking and surface energy. Kim et al. [19] and Kunt et al. [29] emphasized that both cement type and surface preparation significantly influence retention outcomes.

Among surface modification methods, airborne particle abrasion (sandblasting) is considered one of the most effective techniques due to its ability to remove surface contaminants and create micro-retentive irregularities. Ozyetim et al. [21] demonstrated that airborne particle abrasion produced the highest surface roughness and retention values among several techniques, including hydrogen peroxide etching, atmospheric plasma, and chemical mechanical polishing. Similarly, Sahu et al. [12] reported that combined abrasion and sandblasting resulted in the highest retention values, whereas single surface treatments had comparatively lower effects.. In contrast, Reddy et al. [20] reported that sandblasting may not always improve retention and may even have a neutral or negative effect depending on cement type and substrate interaction. These discrepancies indicate that the effect of surface treatment is multifactorial and strongly dependent on cement-surface interactions.

In the present study, no surface roughening was applied to titanium abutments in order to standardize the substrate and isolate the effects of cement type, cement space, and aging conditions. Instead, surface modifications were applied to the internal surfaces of the metal copings. The results demonstrated that surface treatment did not significantly influence retention in any cement group.

Although not statistically significant, a slight increase in retention was observed in temporary cements following diamond bur roughening and sandblasting. This may suggest a potential benefit of surface modification in low-retentive cement systems. The relatively higher effectiveness of sandblasting compared with bur roughening may be attributed to more uniform microstructural changes and increased surface energy rather than simple enlargement of mechanical interlocking sites.

Surface roughness measurements were not performed, as the primary aim of the study was not to characterize surface topography but to evaluate whether different surface treatment modalities influence the retention behavior of the tested cements under standardized conditions.

Aging protocols in in vitro studies are commonly used to simulate the thermal and mechanical challenges encountered during clinical function. However, the number of cycles, applied load, loading frequency, and thermocycling procedures vary considerably among studies. Alvarez-Arenal et al. [23] applied 100,000 loading cycles to evaluate the retention of implant-supported restorations under dynamic loading conditions. Accordingly, in the present study, 100,000 chewing cycles were combined with thermocycling between 5°C and 55°C to simulate thermo-mechanical aging.

In the present study, 100,000 chewing cycles, which has been used in previous studies as an in vitro aging protocol, combined with thermocycling between 5°C and 55°C, were applied according to established protocols. Compared with simplified aging models, this protocol represents a more intensive thermo-mechanical simulation. Previous studies have also employed varying aging strategies; however, most incorporate combined thermal and mechanical loading to better approximate oral conditions.

A study evaluating surface modifications on implant-supported crowns used a simplified protocol consisting of 500 thermocycles and short-term storage. In contrast, the present study applied a combined aging regimen of mechanical and thermal loading, providing a more comprehensive in vitro aging protocol. Despite methodological differences, both approaches emphasize the importance of thermo-mechanical aging in evaluating cement-retained restorations.

Similarly, Veselinović et al. [26] applied thermo-mechanical loading with different parameters, and although methodological differences exist, both studies suggest that aging may influence retention depending on cement type and experimental conditions.

In agreement with these findings, the present study did not identify statistically significant differences in retention between non-aged and aged specimens after 100,000 chewing cycles combined with thermocycling, although minor variations were observed. These findings should be interpreted cautiously, as the absence of a statistically significant difference does not necessarily indicate the absence of an aging effect.

The variability in retention outcomes reported in the literature may be attributed to differences in cement composition, cementation protocols, abutment geometry, surface characteristics, film thickness, and testing methodologies. These factors limit direct comparison between studies and hinder the establishment of a standardized retention threshold that ensures both long-term stability and retrievability of implant-supported restorations.

Limitations

Several limitations should be considered when interpreting the present findings. First, the internal surface characteristics of the crowns, including cement film thickness and potential void formation within the cement layer, were not evaluated. This limits the ability to fully interpret the influence of surface treatments on the behavior of the cement layer. Furthermore, quantitative measurements of surface roughness were not performed following the surface treatment procedures. Therefore, the extent of the changes in surface topography produced by sandblasting and diamond-bur roughening could not be objectively quantified. Second, marginal fit measurements before and after cementation were not performed, which restricts further evaluation of possible changes at the restoration-abutment interface related to cementation procedures. Third, retention was assessed exclusively under tensile loading, which does not fully replicate the complex multidirectional forces present in the oral environment. Therefore, the in vitro findings should be interpreted with caution when extrapolating to clinical conditions. In addition, the exclusive use of full metal crowns may limit the clinical generalizability of the results, as ceramic or porcelain-fused-to-metal restorations may demonstrate different retention behavior due to variations in stiffness, surface characteristics, and cement interaction. Finally, although efforts were made to minimize variability, possible air entrapment associated with manually mixed cements may have influenced the results. However, this was partially controlled by the use of automix systems where applicable.

CONCLUSION

Within the limitations of the present study, the following conclusions can be drawn:

- The type of cement significantly influences the retention of implant-supported fixed prostheses.
- All tested cements demonstrated measurable retention, although significant differences were observed among cement types.
- No statistically significant difference in retention was observed between non-aged and aged specimens after the applied aging protocol.
- Surface roughening of the internal crown surfaces did not produce a statistically significant effect on retention values.
- SEM analysis revealed no observable morphological changes on the titanium surfaces before and after aging under the study conditions.
- Both adhesive and cohesive failure modes were observed, indicating different failure mechanisms depending on cement type.

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