Dental Research Journal

Original Article

Comparison of marginal leakage and retentive strength of implant-supported milled zirconia and cobalt-chromium copings cemented with different temporary cements

Amirreza Hendi[1], Mehran Falahchai[1], Saeid Hasanpour Sigaroodi[2], Hamid Neshandar Asli[1]

[1]Department of Prosthodontics, Dental Sciences Research Center, School of Dentistry, Guilan University of Medical Sciences, [2]School of Dentistry, Guilan University of Medical Sciences, Rasht, Iran

ABSTRACT

Background: Few studies assessed the effect of coping material (particularly milled metal copings) on the retentive strength of cements and reported contradictory results. Thus, this study aims to assess the marginal leakage and retentive strength of implant-supported milled zirconia and cobalt-chromium (Co-Cr) copings cemented with different temporary cements.

Materials and Methods: In this *in vitro* study, Zirconia and Co-Cr copings were fabricated on 100 straight titanium abutments. Each group of copings was divided into five subgroups ($n = 10$) for the use of different cements: permanent zinc-phosphate (ZP) cement, temporary zinc oxide eugenol cement (temp bond [TB]), calcium hydroxide-based temporary cement (Dycal [DC]), polymer-based eugenol-free acrylic-urethane temporary cement (Dentotemp [DT]), and methacrylate-based temporary cement (Implantlink [IL]). The retentive strength and marginal leakage of restorations were assessed. Data were analyzed by one-way ANOVA, Tukey, and Fisher's exact tests ($\alpha = 0.05$).

Results: In the Co-Cr group, the retentive strength values (in Newtons) were as follows: ZP (411.40 ± 5.19) >DC (248.80 ± 5.01) >IL (200.10 ± 5.06) >DT (157.90 ± 5.19) >TB (98.50 ± 6.88). This order was as follows in the zirconia group: ZP (388.70 ± 5.35) >DC (226.60 ± 5.08) >IL (179.00 ± 3.71) >DT (136.00 ± 4.88) >TB (78.60 ± 3.50). All pairwise comparisons were statistically significant ($P < 0.001$). The difference in marginal leakage was not significant among the groups ($P = 0.480$).

Conclusion: The type of coping material and cement type significantly affected retentive strength, but not marginal leakage, of implant restorations. Milled Co-Cr copings showed higher retentive strength than zirconia copings, and ZP cement followed by DC yielded the highest retention.

Key Words: Computer-aided design, dental cements, dental prosthesis, implant-supported

Received: 25-May-2023
Revised: 24-Sep-2023
Accepted: 14-Oct-2023
Published: 27-Nov-2023

Address for correspondence:
Dr. Hamid Neshandar Asli, Department of Prosthodontics, Dental Sciences Research Center, School of Dentistry, Guilan University of Medical Sciences, Rasht-Fooman Road, Rasht, Iran.
E-mail: dr.neshandarasli@yahoo.com

INTRODUCTION

Implant-supported restorations are a popular treatment option for the replacement of lost teeth.[1] These restorations can be cement-retained or screw-retained. Each type of restoration has some advantages and disadvantages and is suitable for certain cases.[2] Nonetheless, the selection of restoration type is mainly based on the preference of the clinician rather than

Access this article online

Website: www.drj.ir
www.drjjournal.net
www.ncbi.nlm.nih.gov/pmc/journals/1480

How to cite this article: Hendi A, Falahchai M, Sigaroodi SH, Asli HN. Comparison of marginal leakage and retentive strength of implant-supported milled zirconia and cobalt-chromium copings cemented with different temporary cements. Dent Res J 2023;20:117.

evidence-based.[3] The advantages of implant-supported cement-retained restorations include optimal esthetics and strength and high durability under occlusal forces since they do not require an occlusal screw access hole.[1] Increased passivity of restoration, uniform stress distribution, easy fabrication, lower laboratory technical sensitivity, lower cost, and faster fabrication process are among the other advantages of implant-supported cement-retained restorations.[4,5] Moreover, cement-retained restorations can be used for cases with inappropriate implant position to correct the occlusion.[2] Nonetheless, cement-retained restorations have some drawbacks as well. Eliminating excess cement from the gingival sulcus is difficult, and residual cement can lead to peri-implantitis.[2] Moreover, the retrieval of cement-retained restorations is challenging.[1]

Marginal leakage and retentive strength are two important factors in implant-supported cement-retained restorations.[1,6,7] Marginal leakage occurs when a gap between the cement and substrate occurs. This gap can lead to the accumulation and proliferation of bacteria.[8] Toxins subsequently accumulate in the area, causing inflammation of peri-implant tissues, especially in restorations with a subgingival margin.[1] The retentive strength of implant restorations should not be too high to prevent their retrieval and should not be too low to cause frequent crown falls and embarrassment to patients.

Cement selection is an important parameter in the durability of implant restorations,[4] which affects both marginal leakage and retention of restoration.[1] An ideal cement should provide adequate retention against the dislodging forces when in function, and allow restoration retrieval for repair.[1] Moreover, cements are different in terms of their resistance to microleakage.[9] Leakage may occur due to the loss of cement adhesion, dissolution of cement, shrinkage of cement, or mechanical failure of cement.[9] Dental cements can be divided into two categories – permanent and temporary cements. Zinc-phosphate (ZP) cement is a permanent cement that has long been used for implant restorations. It is commonly used as a reference for comparison with different cements in the literature.[1] Temporary cements are used for the cementation of provisional restorations, temporary cementation of the final restoration, or cementation of implant-supported restorations.[10] Temporary cements provide optimal retention and marginal seal in implant-supported restorations. On the other hand, due to their elasticity, they allow restoration retrieval, if required.[1] Thus, many researchers recommend the use of temporary cements.[11] Zinc oxide–eugenol (ZOE) and eugenol-free zinc oxide (EF) are the temporary cements used for implant restorations.[12] Recently, temporary urethane-based resin cements were introduced for implant-supported restorations.[3]

The type (material) of implant restoration can also affect its retention and marginal leakage.[11,13-15] Limited studies have compared the retentive strength of zirconia and metal copings cemented with different types of cements, reporting controversial results. Moreover, most available studies have evaluated metal copings fabricated by the conventional casting method, and very limited studies have assessed metal copings fabricated by the milling machine, which has gained recent popularity. Schiessl *et al*.[11] reported no significant difference in the retention of metal and zirconia copings placed on titanium abutments. However, Deepthi *et al*.[13] discussed that each crown type has its considerations when selecting cement type. Despite the availability of studies regarding the retentive strength of different temporary cements used for implant restorations, information regarding the effect of coping materials (especially metal coping fabricated by the computer-aided design-computer-aided manufacturing [CAD-CAM] systems) on retention and marginal leakage is scarce and controversial. Thus, this study aimed to assess the marginal leakage and retentive strength of implant-supported zirconia and cobalt-chromium (Co-Cr) copings cemented with different temporary cements. The null hypothesis was that the type of temporary cement and coping material would have no significant effect on marginal leakage and retention of implant-supported restorations.

MATERIALS AND METHODS

In this *in vitro* study, to calculate the sample size, the formula proportional to the difference between the means of the two communities has been used. Considering the $\beta = 0.80$, $\alpha = 0.05$, and the standard deviation equal to 4.29, 70.76, and $d = 65$, the sample size was equal to at least 9.32 (10 for each group).

$$n = \frac{\left(z_{1-\frac{\alpha}{2}} + z_{1-\beta}\right)^2 \left(\sigma_1^2 + \sigma_2^2\right)}{(d)^2}$$

$$= \frac{(1.96 + 0.84)^2 \left(4.29^2 + 70.76^2\right)}{(65)^2} = 9.32 \cong 10$$

This study evaluated 100 straight titanium abutments (SIC Standard Abutments, SIC invent AG, Basel, Switzerland) with 4.2 mm diameter, 8.5 mm specific height, and 1.5 mm gingival height that were tightened on implant analogs (SIC Lab Implant, SIC invent AG, Basel, Switzerland) with 30 Ncm torque. The abutment and implant analog assemblies were vertically mounted in autopolymerizing acrylic resin blocks (Palapress vario, Heraeus Kulzer, Wehrheim, Germany) using a dental surveyor such that the abutment margin was 2 mm above the acrylic resin. The assemblies were divided into two groups of zirconia and Co-Cr based on the coping material. Each group was subsequently divided into five subgroups (n = 10) based on the type of cement: permanent ZP cement, ZOE cement (temp bond [TB]), temporary cement with a calcium hydroxide base (Dycal [DC]), polymer-based EF acrylic-urethane temporary cement (Dentotemp [DT]), and methacrylate-based temporary cement (Implantlink [IL]). Table 1 presents the details regarding the cements used in this study. ZP cement was used as a standard reference cement since it has a long successful history.[1] The ethical committee at Guilan University of Medical Sciences has approved the study (IR. GUMS. REC.1397.313).

The abutments were scanned by a laboratory scanner (Ceramill Map 400, Amann Girrbach, Koblach, Austria). The copings were then designed by the designing software (Ceramill Mind, Amann Girrbach, Koblach, Austria). The cement space was considered to be 50 µm except at the margins that were fit. An occlusal loop was designed for the zirconia copings. Nonsintered zirconia blocks were then milled by a milling machine (Motion 2 [5x], Amann Girrbach, Koblach, Austria). Eventually, the copings were sintered at 1470°C. Sintered Co-Cr blocks (Zapp AG, Pforzheim, Germany) and a milling machine (Arum 5X; Dowoom, Daejeon, Korea) were used to fabricate metal copings.

The conventional casting method was used to fabricate loop on metal copings such that the wax patterns were invested with a base metal alloy.[16] The loops were then positioned and soldered at the center of the occlusal surface of the copings by using a surveyor. The loops were used to connect the copings to the universal testing machine for the tensile test. After fabrication, the copings' seating was evaluated using silicone disclosing medium (Fit-Checker, GC Corp., Tokyo, Japan). The accuracy of the margins was evaluated by two examiners under ×4. No surface treatment was performed for the substrates. The specimens were cleaned in an ultrasonic bath containing 96% isopropyl alcohol for 5 min. Each cement was mixed according to the manufacturer's instructions and applied on the internal surface of the cervical half of the copings. The copings were then placed on the abutments with finger pressure for 10 s. Subsequently, a 6-kg weight was used to apply pressure along the longitudinal axis of the specimens for 10 min. Excess cement was removed by the sharp tip of an explorer.

All specimens were stored in distilled water at 37°C for 24 h. Subsequently, the specimens were thermocycled for 5000 cycles between 5°C and 55°C with a 30-s dwell time. Each specimen was then immersed in 0.5% aqueous solution of basic fuchsine dye at 37°C for 24 h.[17] To assess the retentive

Table 1: Details of the cements used in this study

Commercial name	Cement type	Composition	Company
Harvard cement (ZP)	ZnO-phosphate	Powder: ZnO, magnesia Liquid: Phosphoric acid	Harvard dental international, Germany, Berlin, Germany
TB	ZnO eugenol	Base: ZnO Catalyzer: Zinc acetate dihydrate, Rosin, oligomers (NLP) and eugenol	Kerr Italia, Salerno, Italy
DC	Calcium hydroxide	Base: 1,3-butylene glycol disalicylate, ZnO, calcium phosphate, calcium tungstate, iron oxide pigments Catalyzer: Calcium hydroxide, N-ethyl-4-toluene sulfonamide, ZnO, titanium dioxide, zinc stearate, iron oxide pigments (only dentin color)	DENTSPLY, Tokyo, Japan
DT	Noneugenol, acrylicurethane polymerbased temporarycement	Catalyst: Aliphatic urethane diacrilate resilient oligomer, TEGDMA, benzoyl peroxide, talc, fumed silica, TiO_2 Base: Aliphatic urethane diacrilate resilient oligomer, TEGDMA, HEMA, co-initiator, talc, fumed silica, TiO_2	Itena clinical, Villepinte, France
IL Semi	Methacrylate–based cement with a plasticizer	Methacrylate oligomers, triclosan	Detax, Ettlingen, Germany

DT: Dentotemp; DC: Dycal; TB: Temp bond; ZnO: Zinc oxide; ZP: Zinc-phosphate; Zp: Zinc-phosphate; TEGDMA: Triethylene glycol dimethacrylate; HEMA: Hydroxyethylmethacrylate strength, the pull-out test was performed using a universal testing machine (STM20; Santam, Tehran, Iran) at a crosshead speed of 0.5 mm/min [Figure 1].

The failure mode was categorized as follows: (I) residual cement on the internal crown surface, (II) residual cement on both crown and abutment surface, and (III) residual cement on the abutment surface.[18]

Moreover, each metal coping was evaluated using a video measuring machine (C-Class Vision Measurement Machine, Easson Optoelectronica Technology Co., Suzhou, China) [Figure 2]. Marginal leakage was quantified according to a classification by Tjan and Chiu[19] as follows:

- Grade 0: No trace of fuchsine dye on the internal surface of the coping (no leakage)
- Grade 1: Leakage limited to the lower half of the internal surface of the coping

Figure 1: Retentive strength test.

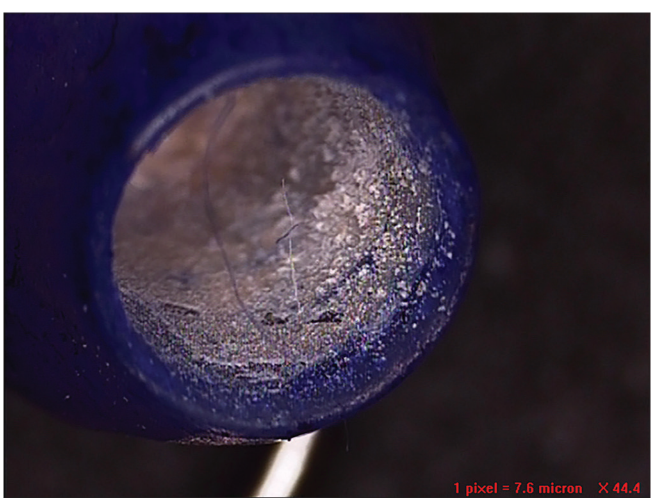

Figure 2: Assessment of basic fuchsine dye penetration into the zirconia coping to determine the leakage grade under a video measuring machine.

- Grade 2: Leakage exceeding the lower half of the internal surface of the coping.

The Shapiro–Wilk test was used to assess the normal distribution of data. The Levene's test was applied to analyze the homogeneity of variances. Since both the assumptions were met, one-way ANOVA and *post hoc* Tukey's test were used to compare the retentive strength among the groups. The Fisher's exact test was used to compare marginal leakage. All statistical analyses were carried out using SPSS version 26 (SPSS Inc., Chicago, IL, USA) at a 0.05 significance level.

RESULTS

Table 2 presents descriptive findings and the results of between-group comparisons. According to the results, the ZP cement yielded the highest retentive strength in both Co-Cr and zirconia coping groups, followed by the DC, IL, DT, and TB. All pairwise comparisons of the cements yielded significant differences ($P < 0.001$). Moreover, Co-Cr copings yielded higher retention, in each cement group than zirconia copings ($P < 0.001$). ZP cement in both Co-Cr (411.40 ± 5.19 N) and zirconia (388.70 ± 5.35 N) copings resulted in higher retentive strength than other cements. After ZP cement, Co-Cr coping with DC cement (248.80 ± 5.01 N) followed by zirconia coping with DC cement (226.60 ± 5.08 N) showed the highest retentive strength. The lowest retentive strength belonged to zirconia coping with TB cement (78.60 ± 3.50 N) followed by Co-Cr coping with TB cement (98.50 ± 6.88 N). Irrespective of coping material, residual cement was found on the crown surface in ZP and DC cement groups, on both the crown and abutment surface in TB, and on the abutment surface in IL and DT groups.

Figure 3 shows the frequency distribution of leakage grades in the study groups. The Fisher's exact test showed no significant difference in marginal leakage between the study groups ($P = 0.480$). Grade 0 was the most common leakage grade in specimens.

DISCUSSION

Cement selection is highly important in all restoration types, particularly implant-supported restorations.[17] Limited studies have addressed the retentive strength and marginal leakage of implant-supported restorations cemented with different temporary

Table 2: Mean and standard deviation of retentive strength of the groups in Newtons (*n*=10)

Group	Co-Cr			Zirconia			*P* (*F*)
	Mean±SD	95% CI for mean		Mean±SD	95% CI for mean		
		Lower bound	Upper bound		Lower bound	Upper bound	
ZP	411.40±5.19[Aa]	407.69	415.11	388.70±5.35[Ab]	384.87	392.53	*P*0.001 (4904.59)
TB	98.50±6.88[Ba]	93.57	103.42	78.60±3.50[Bb]	76.09	81.10	
DC	248.80±5.01[Ca]	245.22	252.38	226.60±5.08[Cb]	222.96	230.23	
DT	157.90±5.19[Da]	154.18	161.62	136.00±4.88[Db]	132.51	139.49	
IL	200.10±5.06[Ea]	196.48	203.72	179.00±3.71[Eb]	176.34	181.65	

Means with the same superscripted uppercase letters within the same column are not significantly different (*P*>0.05). Means with the same superscripted lowercase letters within the same row are not significantly different (*P*>0.05). SD: Standard deviation; ZP: Zinc-phosphate; TB: Temp bond; DC: Dycal; DT: Dentotemp; IL: Implantlink; CI: Confidence interval

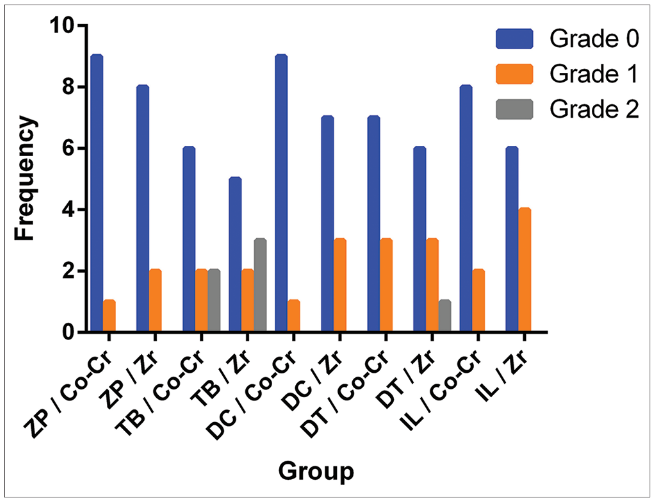

Figure 3: Frequency of leakage grades in the study groups. Co-Cr: Cobalt-chromium, ZP: Zinc-phosphate, TB: Temp bond, DC: Dycal, DT: Dentotemp, IL: Implantlink, Zr: Zirconium.

cements. The present results rejected the part of the null hypothesis regarding no significant effect of cement type and coping material on the retentive strength of implant-supported crowns. Nonetheless, the second part of the null hypothesis regarding no significant effect of cement type and coping material on the leakage grade was confirmed.

Many of the available studies on this topic have high standard deviations,[1,20,21] which can be mainly due to nonstandardization of the fabrication process parameters, particularly the cement layer thickness. Another reason may be the unpredictable behavior of these cements.[22] In the present study, it was tried to standardize the parameters affecting the retentive strength and marginal leakage, other than the cement type and crown material, such as the abutment size and shape, restoration and abutment preparation, cement layer thickness, and the aging process. The use of CAD-CAM technology is one suggested method to standardize the cement layer thickness and shape and dimensions of restorations.[1] Thus, the milling technique was used to fabricate a metal frame, similar to zirconia, and the Co-Cr alloy was directly milled. Moreover, the cementation process was standardized to achieve a cement layer with uniform thickness. The cements were prepared with precise ratios or by the use of mixing tips, and a 6 kg weight was placed on the copings during the setting process of the cement for 10 min.[11] Furthermore, the cement was applied in the cervical half of the copings at the time of cementation. This technique has been shown to decrease marginal leakage and increase retention in implant-supported restorations.[23]

Thermocycling can greatly help predict the long-term clinical service of restorations.[24] Furthermore, it has been shown to be a suitable method for *in vitro* simulation of thermal changes that occur in the oral environment due to eating, drinking, and respiration because restorations are constantly exposed to thermal alterations in the oral cavity.[24,25] In the present study, all specimens were subjected to standard reproducible stress. Aging was performed by thermocycling for 5000 thermal cycles in the present study, corresponding to 4–5 years of clinical service.[26]

The retention of implant-supported restorations plays a fundamental role in treatment success.[5] The present results revealed that the maximum retentive strength was provided by the ZP cement followed by DC, IL, DT, and TB, in an orderly manner, irrespective of the crown material (metal or zirconia). Thus, according to the results, the type of cement affected the retentive strength of implant restorations, and the null hypothesis of the study in this respect was rejected. This finding was in agreement with previous results.[2,4,11,17,18,22,25,27-31] Pan *et al.*[22] found that the retentive strength of the ZP cement was higher than that of temporary cements; however, the difference between ZOE-based temporary cement (TB) and cements with resin and the acrylic base was not significant. Nejatidanesh *et al*.[18,25] in their two studies on zirconia and metal-ceramic crowns, reported results similar to those of Pan *et al*.[22]

This controversy may be due to the use of different brands of resin-based temporary cements in the present study, the study design, and the difference in the material and fabrication technique of restorations. Similarly, Dähne *et al*.[32] evaluated zirconia crowns and reported that IL cement yielded higher retention than TB cement.

An interesting finding of this study was higher retention of DC compared with other temporary cements, including TB. Similarly, Farzin *et al*.[5] assessed implant-supported metal-ceramic restorations, and Román-Rodríguez *et al*.[27] evaluated provisional dental restorations and showed that DC yielded higher retention than the TB cement. In fact, DC, when set, has a more brittle consistency than other temporary cements and is stronger.[5] Moreover, it has been confirmed that ZOE has high solubility in direct contact with water.[4] This finding is in contrast to the results of some studies on provisional dental restorations that did not report a significant difference between DC and Tempbond.[29,33]

The assessment of failure mode is important since removal of residual cement from the abutment surface can be difficult and may damage the surface.[25] According to the results of failure mode assessment in the present study, irrespective of coping material, residual cement was found on the crown surface in ZP and DC cement groups, on both the crown and abutment surface in TB, and on the abutment surface in IL and DT groups. Similar results have been reported in the literature.[18] Nejatidanesh *et al*.[18] evaluated zirconia crowns and reported residual ZP cement only on the crown surface. This finding may be related to the micromechanical retention mechanism of this cement and smoothness of the abutment surface.

The current results regarding the effect of coping material on retentive strength revealed that all cements yielded higher retentive strength in Co-Cr copings compared with zirconia copings. This result was in agreement with that of Lopes *et al*.[2] They found that despite the use of similar milling parameters, Co-Cr copings had higher retentive strength than other copings such as zirconia. The different surface texture and mechanical properties of zirconia and metal alloys can explain this finding. Nonetheless, this finding was in contrast to the results of some other studies. Schiessl *et al*.[11] reported no significant difference in this regard. Another study indicated that the retentive strength of zirconia copings cemented on titanium abutments was higher than that of metal copings.[13] The studies above used metal copings fabricated by the conventional casting method.

Regarding marginal leakage, the current results revealed no significant difference between different cements and also between Co-Cr and zirconia copings in this respect. Similarly, Okuyama *et al*.[17] found no significant difference in marginal leakage between DC and TB cements. This finding was in contrast to the results of some others who reported significant differences in marginal leakage of different cements.[1,17,22] Pan *et al*.[22] demonstrated lower marginal leakage by resin-based temporary cements compared with ZP and by ZP compared with TB. One possible reason for this controversy may be the use of the CAD-CAM system to fabricate copings and the subsequent creation of a standard and uniform cement space, which can improve the seating of restorations. Uniform cement space can enhance the extrusion of excess cement, decrease the required load for seating restoration, and subsequently improve the adaptation and retention of restoration.[22,34] In general, the cement space should be large enough to enhance seating but not too large to excessively increase the cement thickness.[1,35] Evidence shows that an excessively thick cement layer can significantly increase microleakage and bacterial accumulation.[36] Other reasons may be using different brands of cements in studies, different materials for restorations, and different study designs.

In interpreting the present results, it should be noted that this study had an *in vitro* design, and the oral clinical environment cannot be perfectly simulated *in vitro*. A pure tensile test was used in this study while in the oral cavity, tensile forces are only one of many types of forces applied to restorations in the process of mastication that may cause decementation. However, similar studies also used this test, which allows a more accurate comparison of the results. Future clinical studies are required, taking into account the abovementioned limitations.

CONCLUSION

By taking into account the limitations of this *in vitro* study, it may be concluded that the coping material and cement type can affect the retention of implant-supported restorations such that Co-Cr copings and DC cement (of all temporary cements tested in this study) yielded higher retention. Nonetheless, marginal leakage was not influenced by the coping material or cement type, and most restorations showed a low grade of leakage.

Acknowledgment

Our grateful thanks are extended to Dr. Mohammad Ebrahim Ghaffari with a PhD degree in Biostatistics for his help in doing the meteorological data analysis.

Financial support and sponsorship

This work was supported by the Dental Research Center Dentistry Research Institute of Guilan University of Medical Sciences, Guilan, Iran (grant # IR.GUMS.REC.1397.313).

Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

REFERENCES

1. Saleh M, Taşar-Faruk S. Comparing the marginal leakage and retention of implant-supported restorations cemented by four different dental cements. Clin Implant Dent Relat Res 2019;21:1181-8.
2. Lopes AC, Machado CM, Bonjardim LR, Bergamo ET, Ramalho IS, Witek L, *et al.* The effect of CAD/CAM crown material and cement type on retention to implant abutments. J Prosthodont 2019;28:e552-6.
3. Alvarez-Arenal A, Gonzalez-Gonzalez I, deLlanos-Lanchares H, Brizuela-Velasco A, Ellacuria-Echebarria J. The selection criteria of temporary or permanent luting agents in implant-supported prostheses: *In vitro* study. J Adv Prosthodont 2016;8:144-9.
4. Sarfaraz H, Hassan A, Shenoy KK, Shetty M. An *in vitro* study to compare the influence of newer luting cements on retention of cement-retained implant-supported prosthesis. J Indian Prosthodont Soc 2019;19:166-72.
5. Farzin M, Torabi K, Ahangari AH, Derafshi R. Effect of abutment modification and cement type on retention of cement-retained implant supported crowns. J Dent (Tehran) 2014;11:256-62.
6. Aladag A, Sahan MH, Akkus NO, Aktas R. Retention of luting agents used for implant-supported restorations: A comparative *in-vitro* study. Niger J Clin Pract 2020;23:1073-8.
7. Handa M, Marya P, Gupta V, Chopra S. Comparative evaluation of microleakage of metallic copings luted with three different commercially available luting cements: An *in vitro* study. J Indian Prosthodont Soc 2021;21:57-65.
8. Falahchai M, Babaee Hemmati Y, Neshandar Asli H, Emadi I. Marginal gap of monolithic zirconia endocrowns fabricated by using digital scanning and conventional impressions. J Prosthet Dent 2021;125:325.e1-5.
9. Amina SA, Rajput G, Ahmed S, Chaturvedi S, Addas MK, Bhagat TV, *et al.* Comparison of microleakage in nanocomposite and amalgam as a crown foundation material luted with different luting cements under CAD-CAM milled metal crowns: An *in vitro* microscopic study. Polymers (Basel) 2022;14:2609.
10. Gross G, Schmohl L, Fuchs F, Guenther E, Schulz-Siegmund M, Schoengart J, *et al.* Retention force, translucency, and microstructural properties of translucent temporary luting cements: An *in vitro* study. J Mech Behav Biomed Mater 2023;142:105781.
11. Schiessl C, Schaefer L, Winter C, Fuerst J, Rosentritt M, Zeman F, *et al.* Factors determining the retentiveness of luting agents used with metal- and ceramic-based implant components. Clin Oral Investig 2013;17:1179-90.
12. Almehmadi N, Kutkut A, Al-Sabbagh M. What is the best available luting agent for implant prosthesis? Dent Clin North Am 2019;63:531-45.
13. Deepthi B, Mallikarjuna D, Shetty MS. Comparative evaluation of retention of zirconia copings and cast metal copings cemented onto titanium abutments: An *in vitro* study. J Interdiscip Dent 2019;9:8.
14. Nejatidanesh F, Shakibamehr AH, Savabi O. Comparison of marginal and internal adaptation of CAD/CAM and conventional cement retained implant-supported single crowns. Implant Dent 2016;25:103-8.
15. Rengasamy S, Nair KC, Shetty J. Effect of luting agents and height of implant abutments on the retentive properties of copings-an *in vitro* study. Acta Sci Dent Sci 2023;7:79-90.
16. Hendi AR, Moharrami M, Siadat H, Hajmiragha H, Alikhasi M. The effect of conventional, half-digital, and full-digital fabrication techniques on the retention and apical gap of post and core restorations. J Prosthet Dent 2019;121:364.e1-6.
17. Okuyama JY, de Brito RB Jr., França FM. Aluminum oxide sandblasting of hexagonal coping and abutment: Influence on retention and marginal leakage using temporary cements. Implant Dent 2016;25:394-9.
18. Nejatidanesh F, Savabi O, Shahtoosi M. Retention of implant-supported zirconium oxide ceramic restorations using different luting agents. Clin Oral Implants Res 2013;24 Suppl A100:20-4.
19. Tjan AH, Chiu J. Microleakage of core materials for complete cast gold crowns. J Prosthet Dent 1989;61:659-64.
20. Dudley JE, Richards LC, Abbott JR. Retention of cast crown copings cemented to implant abutments. Aust Dent J 2008;53:332-9.
21. Squier RS, Agar JR, Duncan JP, Taylor TD. Retentiveness of dental cements used with metallic implant components. Int J Oral Maxillofac Implants 2001;16:793-8.
22. Pan YH, Ramp LC, Lin CK, Liu PR. Retention and leakage of implant-supported restorations luted with provisional cement: A pilot study. J Oral Rehabil 2007;34:206-12.
23. Liang T, Hu X, Zhu L, Pan X, Zhou Y, Liu J. Comparative *in vitro* study of cementing techniques for implant-supported restorations. J Prosthet Dent 2016;116:59-66.
24. Michalakis K, Pissiotis AL, Kang K, Hirayama H, Garefis PD, Petridis H. 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. Int J Oral Maxillofac Implants 2007;22:569-74.
25. Nejatidanesh F, Savabi O, Ebrahimi M, Savabi G. Retentiveness of implant-supported metal copings using different luting agents. Dent Res J (Isfahan) 2012;9:13-8.
26. Stawarczyk B, Bähr N, Beuer F, Wimmer T, Eichberger M, Gernet W, *et al.* Influence of plasma pretreatment on shear bond strength of self-adhesive resin cements to polyetheretherketone. Clin Oral Investig 2014;18:163-70.
27. Román-Rodríguez JL, Millan-Martínez D, Fons-Font A, Agustín-Panadero R, Fernández-Estevan L. Traction test of temporary dental cements. J Clin Exp Dent 2017;9:e564-8.
28. Kapoor R, Singh K, Kaur S, Arora A. Retention of implant supported metal crowns cemented with different luting agents: A comparative *in vitro* study. J Clin Diagn Res 2016;10:C61-4.
29. Rego MR, Santiago LC. Retention of provisional crowns cemented with eight temporary cements: Comparative study. J Appl Oral Sci 2004;12:209-12.
30. Bernal G, Okamura M, Muñoz CA. The effects of abutment taper, length and cement type on resistance to dislodgement of cement-retained, implant-supported restorations. J Prosthodont 2003;12:111-5.
31. Mehta S, Kesari A, Tomar M, Sharma U, Sagar P, Nakum P, *et al.* An evaluation of the effectiveness of various luting cements on the retention of implant-supported metal crowns. Cureus 2023;15:e41691.
32. Dähne F, Meißner H, Böning K, Arnold C, Gutwald R, Prause E. Retention of different temporary cements tested on zirconia crowns and titanium abutments *in vitro*. Int J Implant Dent 2021;7:62.
33. Lepe X, Bales DJ, Johnson GH. Retention of provisional crowns fabricated from two materials with the use of four temporary cements. J Prosthet Dent 1999;81:469-75.
34. Dixon DL, Breeding LC, Lilly KR. Use of luting agents with an implant system: Part II. J Prosthet Dent 1992;68:885-90.
35. Gultekin P, Gultekin BA, Aydin M, Yalcin S. Cement selection for implant-supported crowns fabricated with different luting space settings. J Prosthodont 2013;22:112-9.
36. Gönder HY, Fidancıoğlu YD, Fidan M, Mohammadi R, Karabekiroğlu S. Comparison of resin cement's different thicknesses and Poisson's ratios on the stress distribution of class II amalgam restoration using finite element analysis. Appl Sci 2023;13:4125.