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ORIGINAL ARTICLE

Factors determining the retentiveness of luting agents used with metal- and ceramic-based implant components

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Abstract
Objectives To investigate the factors that determine the retentiveness of copings made of cobalt–chromium (CoCr)-alloy or zirconia luted with permanent (solid-body like) and provisional (viscous, elastic-body-like) luting agents.
Materials and methods We manufactured titanium implant analogs with four-, six-, and eight-taper degrees and copings of CoCr-alloy and zirconia and luted the copings according to a standardized protocol. Samples were thermally cycled, and we investigated the various degrees of roughness of the copings' inner surfaces as well as the various cement mixing ratios on the retentiveness. Copings were either pulled out slowly (by means of a universal testing machine) or knocked out quickly (using a CORONAflex crown replacement device).
Results The highest level of retentiveness was achieved with a four-taper degree for polycarboxylates followed by zinc-oxide-phosphates and glass ionomers or composite cements. Provisional cements and composite cements containing a plastifier showed significantly lower retentiveness levels. The pull-out and knock-out tests showed a relationship between retentiveness level and taper degree. However, the influence of taper degree was reduced with higher taper degrees as well as with cements that do not set as a solid body due to ingredients such as oily liquids or plastifiers. Thermal cycling further reduced the retentiveness level of these cements. Higher degrees of roughness only improved the retention force of cements setting as a solid body. Mixing errors may alter retentiveness levels in an unpredictable manner. When used within the same group of cements, metal-alloy, and zirconia copings did not differ with regard to their level of retentiveness.
Conclusion Copings made of metal-alloy and zirconia showed no different level of retentiveness when set onto titanium abutments fixed with permanent or provisional cements.
Clinical relevance Only cements setting as a solid body showed a clear relationship between retentiveness level and taper degree. In contrast, the retentiveness of provisional (viscous, elastic-body-like) luting agents was less predictable.

Keywords Retentiveness · Copings · Metal-alloy · Zirconia · Pull-out test · Knock-out test · Luting agent

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Introduction

When dental implants became a new treatment option more than 30 years ago, dentists debated whether restorations should be cemented onto abutments or rather fixed with screws [1, 9, 10, 15, 16, 19, 25]. The advantages and disadvantages of both procedures have been described in the literature; Table 1 lists the core benefits and shortcomings of both methods.

The decision of a dentist on the method of luting a restoration onto an abutment is followed by the question of what type of cement should be used. Many authors have recommended provisional cements [11, 14, 22] that allow an easy removal of cement remnants. Furthermore, the retention force of cements is most adequate for fixing restorations onto abutments. The core benefit of provisional cements is that they allow the retrieval of a restoration without damaging the implant abutment. However, other authors have emphasized that restorations made with more recently developed dental implant systems have a long-lasting prognosis equivalent to

Table 1 The core benefits and shortcomings of screw-retained and cemented methods

	Screw-retained	Cemented
Advantages	Retrievability of the restoration [19, 25]	Easy handling
		Cheap manufacture
		Retrievability possible by using provisional cements
		No screw visible, better esthetic [9–11, 15, 16, 19, 26]
		Cement fills possible marginal gaps preventing microorganisms from colonizing the inner part of the implant [13, 22, 24]
Disadvantages	Screw loosening [1, 9, 10, 15, 16, 19]	Loss of retention [9, 10]
	Screw fracture Screw limits occlusal reconstruction [26]	Remnants of cements in the sulcus cause periodontitis (1997, [23])

that of prostheses fixed onto natural teeth [4]. Therefore, retrievability may have ceased to be the central problem. Other risks are debonding of the restoration and cement wash-out; however, these risks as well as the opaque appearance of provisional luting agents can be avoided by using permanent cements, such as glass ionomers, polycarboxylates, or resin-based cements.

Although the method of luting fixed dentures onto dental implant abutments has been used extensively, few clinical data are available [11]. Thus, most recommendations of luting protocols are based on laboratory studies. Typically, uni-axial pull-out tests have been conducted [17], in which metal-based copings or crowns are pulled out with low cross-head speeds of 0.1 to 5 mm/min using metallic abutments with various taper degrees and abutment lengths or widths [3, 5, 12, 17, 20].

Pull-out tests with various cements have shown that taper degree and abutment height affect the degree of retention more than width or the total surface of the abutment. So far, implant and natural teeth abutments have not differed [3, 5, 27].

However, some questions are still unanswered. The uni-axial retention force test only applies low-speed removal forces on a restoration, which does not correspond to forces present during mastication. Therefore, knock-out forces including fast-speed removal forces also occur [18]. In our investigation, we therefore conducted both a pull-out and a knock-out test. We hypothesized that the retentiveness levels of cements depend on the test design used, which affects the ranking of luting agents with regard to the level of retentiveness. A further influence on cement retentiveness may be aberrant ratios of powder and liquid [2], various degrees of roughness of the inner surfaces of the crown-bases, aging procedures such as thermal cycling [12], and, last but not least, different crown-base materials such as zirconia or metal alloys [21]. In our study, we hypothesized

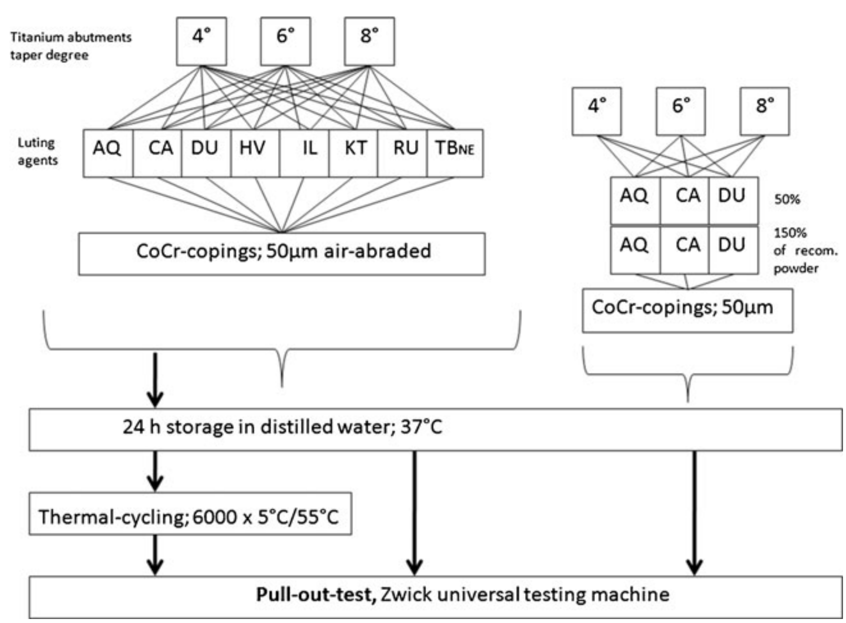


Fig. 1 Scheme of pull-out tests with CoCr copings; the inner surfaces were air-abraded with 50 µm Al_2O_3

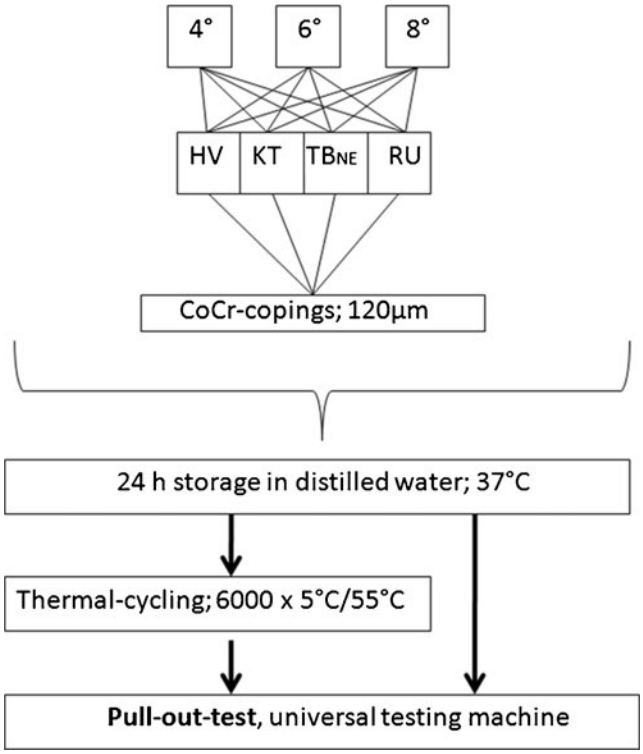


Fig. 2 Scheme of pull-out test using CoCr copings; the inner surfaces were air-abraded with 120 μm Al_2O_3

that copings made of zirconia or metal alloys with different surface textures will show different levels of retentiveness on titanium implant abutments with various taper degrees and luting agents. So far, all cements of one category, for instance polycarboxylates, have been assumed to have comparable retentiveness levels. However, according to clinical observations, we hypothesized that luting agents within different categories (e.g., polycarboxylates) show different levels of retentiveness on dental implant abutments.

Materials and methods

Principle test design

Cobalt–chromium (CoCr; n=840) and zirconia (n=360) copings were fixed onto titanium abutments with different luting agents and then uni-axially pulled out or knocked out. The influence of aging, roughness of the inner surfaces of the copings, mixing errors, and taper degree has been investigated using special subgroups. Figures 1, 2, 3, and 4 depict all conducted investigations.

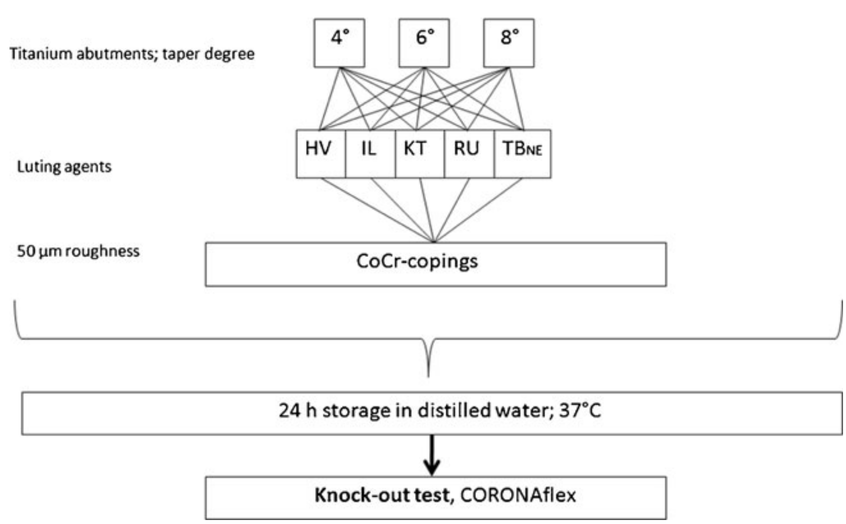
Construction and preparation of abutments

Titanium implant analogs (n=1200; grade 4) with four-, six-, and eight-taper degrees were milled with a copy-milling machine. In each case, 400 analogs of each taper degree were constructed. The abutments of these analogs were 6 mm in height and 4.1 mm in diameter in the section of the chamfer finish line (Fig. 5).

Construction of cobalt–chromium copings

Copings were waxed up on four-, six-, and eight-taper degree abutments (altogether n=840). A hook was applied on top of each coping, allowing the application of a pull-out or knock-out force (Fig. 5). The wax patterns were invested in phosphate-based investment material and cast with CoCr-alloy (Wirobond LFC; BEGO, Bremen, Germany; Co 33 wt%, Cr 30 wt%, Fe 29 wt%, Mo 5 wt%, Mn 1.5 wt%, Si 1.0 wt%). After the casting, we checked the fit of the copings on their corresponding abutment tapers by means of thinly flowing silicone impression material (Xantopren; Heraeus-Kulzer, Hanau, Germany). The inner surfaces of the copings were air-abraded with 50 μm Al_2O_3 at 2.5 bar

Fig. 3 Scheme of knock-out tests using CoCr copings



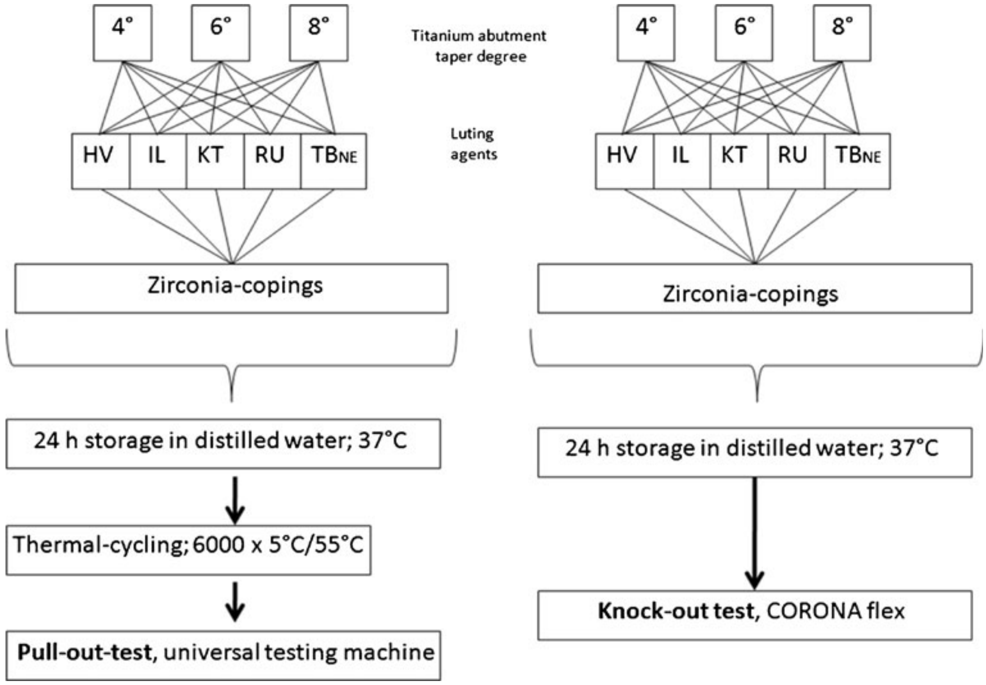


Fig. 4 Scheme of pull-out tests and knock-out tests with zirconia copings

for 20 s. Copings and abutments were degreased in 70 % alcohol, steam-cleaned, and dried and then assigned to subgroups of eight specimens each.

Additionally, we constructed 192 CoCr copings according to the above-mentioned process. The inner surfaces of these copings, however, were air-abraded with 120 µm Al_2O_3 at 2.5 bar for 20 s.

Zirconia specimens

All in all, we constructed 360 zirconia copings (Cercon; DeguDent, Hanau, Germany). Copings were waxed up on the abutments of four-, six-, and eight-taper degrees. Hooks were added to the top of each coping, which should allow the application of a pull-out or knock-out force at a later stage (Fig. 6). The wax models were scanned with a Cercon brain device (DeguDent, Hanau, Germany). On the basis of these scans, we made copings for all three taper degrees with the Cercon brain-milling system using "Cercon base" blanks (93 wt% zirconia di-oxide, 5 wt% yttrium oxide, >2 wt% hafnium oxide, >1 wt% aluminum oxide and silicon oxide). After the milling, the copings were set in the "Cercon heat" sintering furnace tray and sintered at a temperature of 1,350 °C for 7 h. The inner surfaces of the copings were air-abraded with 50 µm Al_2O_3 at 2.5 bar for 20 s, then degreased in 70 % alcohol, steam-cleaned, and dried. The copings were randomly assigned to subgroups of eight specimens each.

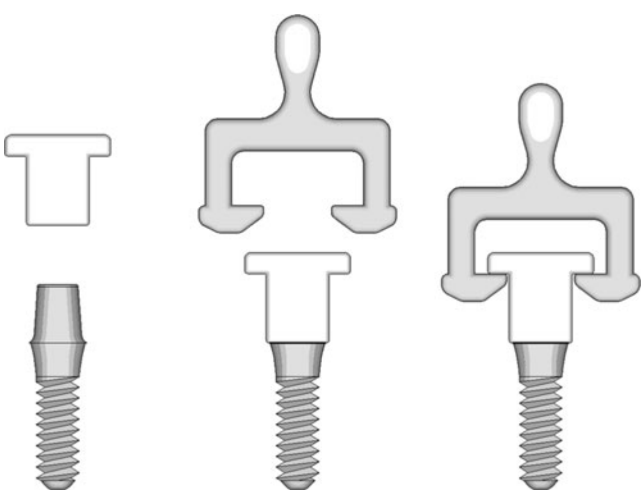


Fig. 5 Scheme of dental implant analog, coping, and retraction device

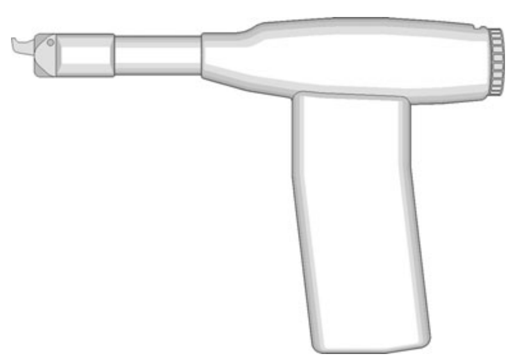


Fig. 6 CORONAflex device

Table 2 Cement types and brands used in this investigation

Name	Abbreviation	Type	Property after setting	Company	Mixing ratio
Aqualox	AQ	Water mixable zinc polycarboxylate cement	Solid-body like	VOCO, Cuxhaven, Germany	5.5:1 P/L
Carboco	CA	Zinc polycarboxylate cement	Solid-body like	VOCO, Cuxhaven, Germany	3:1 P/L
Durelon	DU	Zinc polycarboxylate cement	Solid-body like	3M ESPE, Seefeld, Germany	2:1 P/L
Harvard Cement	HV	Zinc-oxide-phosphate	Solid-body like	Hofmann, Berlin, Germany	1.8:1 P/L
ImplantLink	IL	Methacrylate–based cement with a plasticizer	More elastic –body like	Detax, Ettlingen, Germany	4:1 B/C
Ketac Cem	KC	Glass ionomer cement	Solid-body like	3M ESPE, Seefeld, Germany	3.8:1 P/L
RelyX Unicem	RU	Self-adhesive methacrylate based cement	Solid-body like	3M ESPE, Seefeld, Germany	1:1 B/C
Temp Bond NE	TB	Zinc-oxide eugenol free	More highly viscous liquid-body like	Kerr, Rastatt, Germany	1:1 B/C

Luting agents

We investigated the provisional and permanent luting agents shown in Table 2. The ratio between powder and liquid or pastes and catalysts followed the manufacturer's recommendations (Table 2). Chemical balance (Sartorius, Göttingen, Germany) was weighted with a tolerance limit of ±0.1 mg powder and liquid or the pastes of the luting agents. Ketac Cem and RelyX Unicem, which were delivered in capsules containing both powder and liquid in the recommended ratio, were mixed in a CapeMix shaker (3M ESPE, Seefeld, Germany) for 15 s. All cements were mixed at room temperature. Mixed cement was filled up to the copings, and the copings were seated onto the abutments. A weight of 1.8 kg was applied to the copings for 10 min. After the setting, we removed excess cement with scalers.

The cement category of polycarboxylates was chosen for evaluating the influence of aberrant mixing ratios of powder and liquid on the level of retentiveness. Starting with the recommended powder-to-liquid ratio, we then produced mixings containing 50 and 150 % more powder. This group of cements should disprove the frequently mentioned hypothesis, that all cements of a group had similar levels of retentiveness, so that any

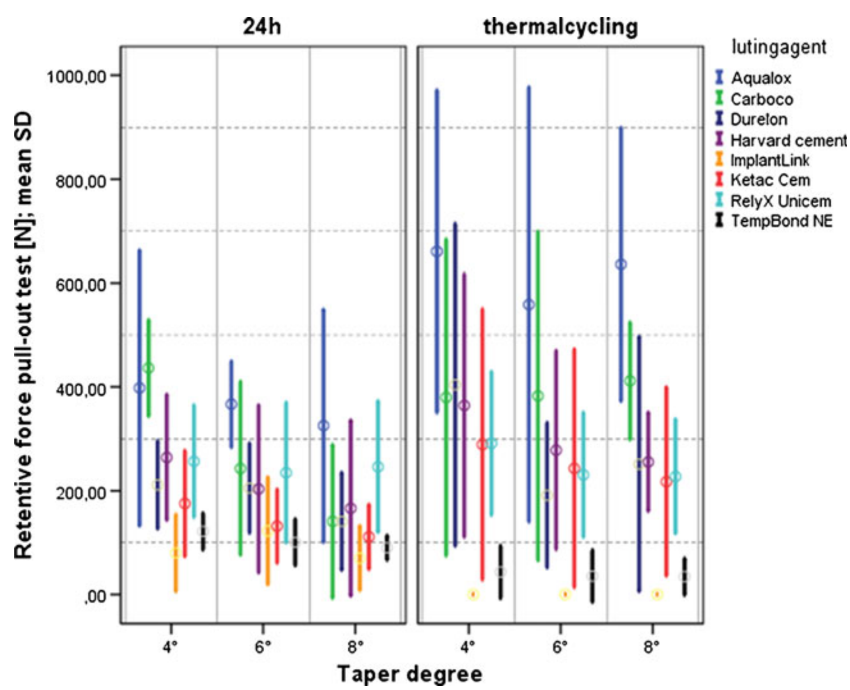


Fig. 7 Pull-out test of CoCr copings with 50 μm roughness. Comparison of results after 24 h water storage and after 6,000 thermal cycles at 5 and 55 °C. Statistics: please see Table 3

Table 3 Univariate variance analysis: pull-out test of CoCr copings with various cements (see Fig. 7)

F value	Sig.
Main factor: luting agent; $F(7,642)=231.54$	0.0001
Main factor taper degree; $F(2, 647)=37.86$	0.0001
Main factor aging; $F(1,648)=95.63$	0.0001
Interaction luting agent×taper degree; $F(14,635)=2.97$	0.0001
Interaction luting agent×aging; $F(7,642)=37.55$	0.0001
Interaction taper degree×aging $F(2,647)=7.75$	0.0001
Interaction luting agent×taper degree×aging; $F(14,635)=3.84$	0.0001

Luting agents: Ketac Cem, Harvard Cement, Temp Bond NE, Implant Link, RelyX Unicem, Carboco, Aqualox, Durelon. Aging, 24 h; thermalcycling (TC). Taper degree: 4°, 6°, 8°

randomly picked cement brand of this group represented the entire category "cement".

Aging procedure

Ten minutes after cementation, the specimens were stored in distilled water at 37 °C for 24 h. Then, all copings of the 24-h test were either pulled out or knocked out. The remaining specimens of the pull-out test were thermally cycled, undergoing 6,000 cycles in distilled water at 5 and 55 °C. The temperature changed every 2 min.

Pull-out tests and knock-out tests

A Zwick 1446 universal testing machine (Zwick, Ulm, Germany) pulled out the luted copings at a cross-head speed of 1 mm/min. The pull-out force worked uni-axially. The force-detecting system of the machine interpreted decreases by 10 % in maximally registered retentive strength levels as debonding and stopped the pull-out test. Figure 5 depicts the pull-out device (Fig. 5).

The knock-out test was conducted by means of the CORONAflex system (KaVo; Leutkirch, Germany) (Fig. 6). This system is normally used for the removal of crowns or FPDs from natural teeth abutments. A piston is accelerated along a shaft into the tip of the crown remover by means of compressed air. The resulting short impact pulse acts on the structure of the cement, destroying it abruptly and thus eliminating the adhesion. The knocks necessary for removing the luted copings from the abutments were counted. For all types of cement, we first used the sequence "high force". However, for the provisional cements Implantlink and TempBond NE, we also used the sequence "low force" because the copings lost retention after only one or two strokes with the "high force" mode.

Statistics

We calculated means and standard deviations and determined statistically significant differences by means of the univariate

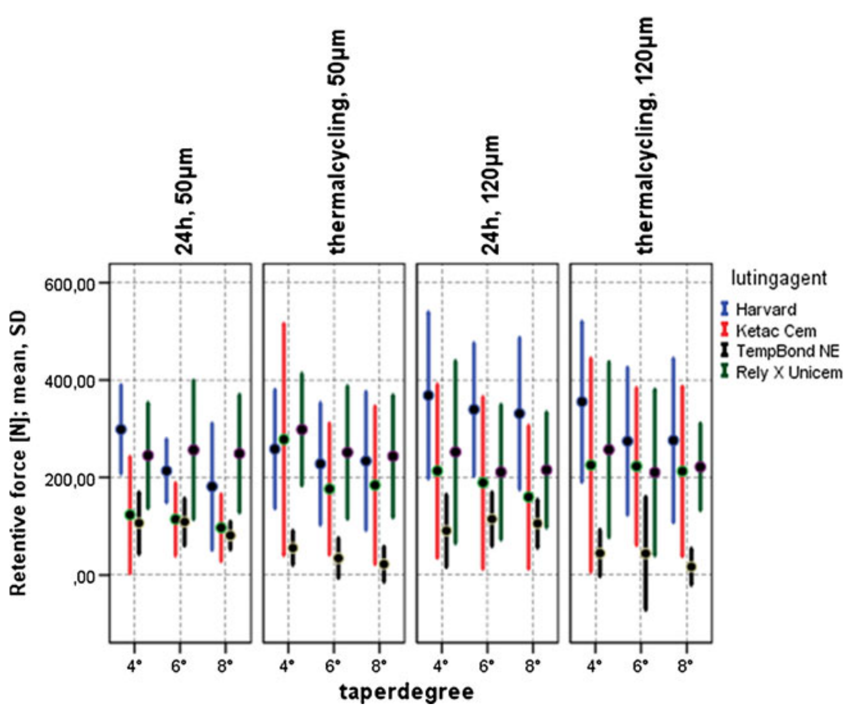


Fig. 8 Pull-out test of CoCr copings with 50 and 120 µm roughness. Comparison of results after 24 h water storage and after 6,000 thermal cycles at 5 and 55 °C. Statistics: please see Table 4

Table 4 Univariate variance analysis: pull-out test of CoCr copings with various roughness (see Fig. 8)

F value	Sig.
Main factor: luting agent; $F(3,380)=148.45$	0.0001
Main factor taper degree; $F(2, 381)=12.17$	0.0001
Main factor roughness; $F(1,382)=16.32$	0.0001
Main factor aging; $F(1,382)=0.22$	0.637
Interaction luting agent×taper degree; $F(6,377)=1.65$	0.131
Interaction luting agent×roughness; $F(3,380)=9.31$	0.0001
Interaction luting agent×aging; $F(3,380)=14.85$	0.0001
Interaction taper degree×roughness; $F(2,381)=1.24$	0.291
Interaction taper degree×aging; $F(2,381)=3.01$	0.05
Interaction roughness×aging; $F(1,382)=1.28$	0.257
Interaction luting agent×taper degree×aging; $F(6,377)=1.22$	0.295
Interaction luting agent×taper degree×roughness; $F(6,377)=1.28$	0.262
Interaction luting agent×roughness×aging, $F(3,381)=0.55$	0.647
Inter action luting agent×taper degree×roughness×aging; $F(6,377)=1.23$	0.286

Luting agents: Ketac Cem, Harvard Cement, Temp Bond NE, RelyX Unicem. Taper degree, 4°, 6°, 8°. Roughness, 50 and 120 µm. Aging: 24 h; thermalcycling (TC)

variance analysis (SPSS 19.0 for Windows, SPSS Inc., Chicago, USA). Test variables were "luting agent", "coping-material", "taper degree", "aging" "coping roughness" and their interceptions. Post hoc tests were performed and adjusted by Bonferroni. The level of significance was set at $\alpha=0.05$.

Results

CoCr copings pull-out test

The retentiveness levels of the luting agents differed significantly. Three groups can be differentiated: The first group with the polycarboxylates Aqualox and Carboco showed the highest pull-out forces. The second group with Durelon, Harvard Cement, KetacCem, and RelyX Unicem showed a moderate level of retentiveness. The third group with the provisional cements Implantlink and Temp Bond NE showed the lowest level of retentiveness (Fig. 7; Table 3).

All luting agents showed that the taper degree determined their level of retentiveness. The means were highest with the four-taper degree, decreased with the six-taper degree, and were lowest with the eight-taper degree. However, the impact of the taper degree was minor for provisional cements that showed the lowest level of retentiveness after thermal cycling. Implantlink completely lost retention during the aging procedure, whereas TempBond NE had very low pull-out forces independent of the taper degree. All other cements

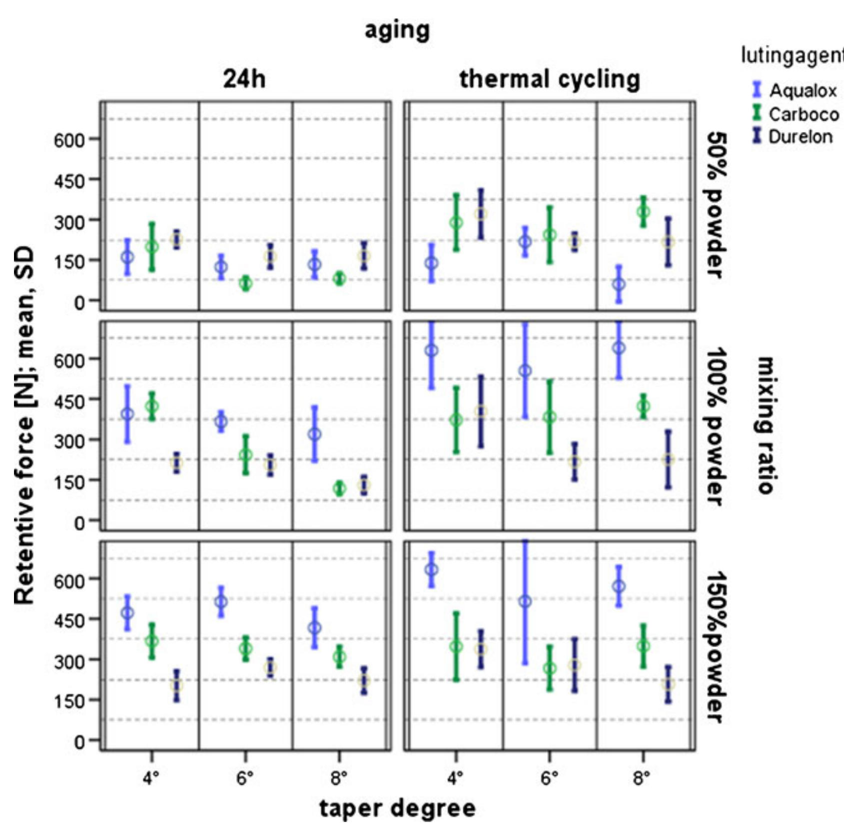


Fig. 9 Pull-out test of CoCr copings. Polycarboxylate cements were mixed with various amounts of powder and liquid. Comparison of results after 24 h water storage and after 6,000 thermal cycles at 5 and 55 °C. Statistics: please see Table 5

Table 5 Univariate variance analysis: pull-out test of CoCr copings luted with carboxylate of various mixing ratios (see Fig. 9)

F value	Sig.
Main factor: luting agent; $F(2,430)=82.29$	0.0001
Main factor taper degree; $F(2, 430)=18.69$	0.0001
Main factor mixing ratio; $F(2,430)=147.90$	0.0001
Main factor aging; $F(1, 431)=99.48$	0.0001
Interaction luting agent×taper degree; $F(4,428)=1.41$	0.228
Interaction luting agent×mixing ratio; $F(4,428)=50.26$	0.0001
Interaction luting agent×aging, $F(4,428)=2.13$	0.119
Interaction taper degree×mixing ratio; $F(2,428)=1.07$	0.366
Interaction taper degree×aging; $F(2,431)=3.15$	0.044
Interaction mixing ratio×aging; $F(2,431)=13.06$	0.0001
Interaction luting agent×taper degree×mixing ratio; $F(8,424)=1.53$	0.144
Interaction luting agent×taper degree×aging; $F(4,428)=6.79$	0.0001
Interaction luting agent×mixing ratio×aging; $F(4,428)=9.87$	0.0001
Interaction taper degree×mixing ratio×aging; $F(4,428)=4.04$	0.003
Interaction luting agent×taper degree×mixing ratio×aging; $F(8,424)=1.66$	0.105

Luting agents: Aqualox, Carboco, Durelon. Taper degree, 4°, 6°, 8°. Mixing ratio, 50 % recommended powder, 100 % recommended Powder, 150 % recommended powder Aging: 24 h, thermalcycling

showed a higher level of retentiveness after thermal cycling.

Higher degrees of roughness of the inner surfaces of the copings resulted in a statistically significant increase in the level of retentiveness for Harvard Cement and Ketac Cem (Fig. 8; Table 4) that showed a linear increase in retentiveness levels from a eight-taper degree to a six- and four-taper degree. In contrast, neither roughness nor the taper degree seemed to have any or only little impact on the level of retentiveness for TempBond NE and RelyX Unicem. Thermal cycling improved the level of retentiveness of copings air-abraded with 50 µm and luted with Harvard cement or Ketac Cem. However, higher roughness degrees of 120 µm air-abrading and thermal cycling showed levels of retentiveness comparable with those of 50 µm air-abrading. Again, the provisional cement TempBond NE had considerably lower levels of retentiveness after thermal cycling, which could not be improved by higher roughness degrees of the inner surfaces of the copings.

Mixing errors with polycarboxylates; CoCr copings; pull-out test

Use of more powder than recommended increased the level of retentiveness of the cements, whereas use of less powder decreased the level (Fig. 9; Table 5). Aberrant powder and liquid ratios made the behavior of the cements less predictable. Aqualox showed the highest retentive forces with both the recommended powder ratio and the 150 % powder ratio, but this cement showed the lowest level of retentiveness when mixed with a powder ratio of 50 % only. Although each of the three luting agents belonged to the category of polyoxycarbolates, their levels of retentiveness and their performance were rather different. These differences increased when the polyoxycarbolates were mixed with

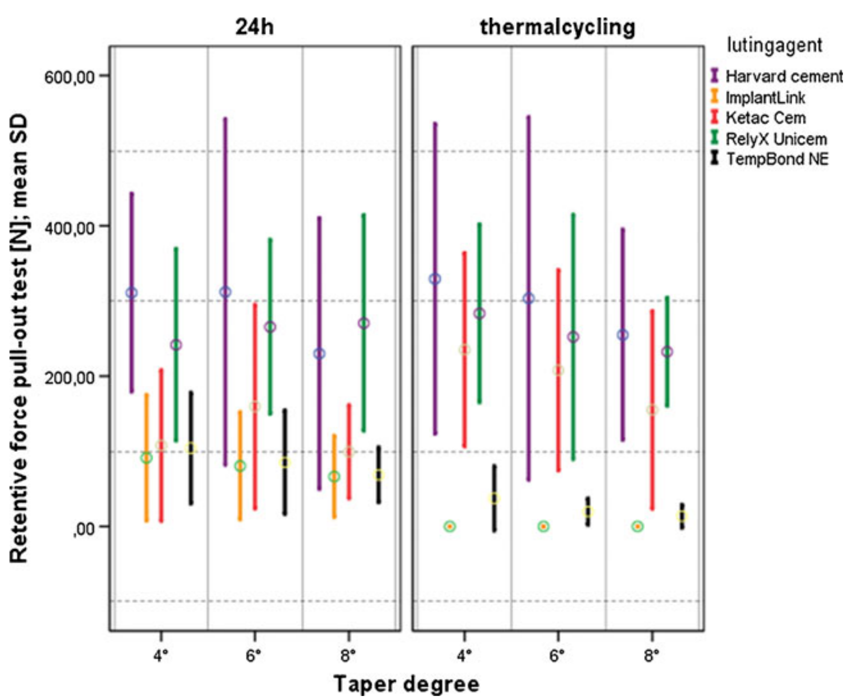


Fig. 10 Pull-out test of zirconia copings. Comparison of results after 24 h water storage and after 6,000 thermal cycles at 5 and 55 °C. Statistics: please see Table 6

Table 6 Univariate variance analysis: pull-out test of zirconia copings (see Fig. 10)

F value	Sig.
Main factor: luting agent; $F(4,566)=384.44$	0.0001
Main factor taper degree; $F(2, 568)=17.02$	0.0001
Main factor aging; $F(1, 569)=4.14$	0.042
Interaction luting agent × taper degree; $F(8,562)=3.06$	0.002
Interaction luting agent × aging, $F(4,576)=28.09$	0.0001
Interaction taper degree × aging; $F(2,568)=2.96$	0.053
Interaction luting agent × taper degree × aging; $F(8,562)=2.25$	0.023

Luting agents: Ketac Cem, Harvard Cement, Temp Bond NE, Implant Link, RelyX Unicem. Taper degree, 4°, 6°, 8°. Aging: 24 h, thermalcycling

aberrant powder and liquid ratios or after thermal cycling. The recommended powder and liquid ratio was linearly dependent on the level of retentiveness and the taper degree; however, this dependence ceased when aberrant mixing ratios were used.

Zirconia copings pull-out test

Compared to CoCr copings, the retentiveness levels of zirconia copings were similar for Harvard Cement, Ketac Cem, RelyX Unicem, as well as for the provisional cements Implantlink and TempBond NE (Fig. 10; Table 6). Again, the taper degree influenced the retention force, and the provisional cements also failed after thermal cycling and showed no (Implantlink) or only very low (TempBondNE) retention force.

However, parameters of the pull-out forces of Harvard Cement, KetacCem, and RelyX Unicem increased only very slightly after thermal cycling, which stood in contrast to the considerably higher rise for CoCr copings.

Knock-out tests

The low level of retentiveness of provisional cements requires the additional use of a low knock-out force (Figs. 11 and 12; Tables 7 and 8). The coping material—zirconia or CoCr—did not affect the results. When using the same luting agent and taper degree, both materials needed a comparable number of impact pulses for the removal of a coping. We could again observe the impact of the taper degree on the level of retentiveness that seemed to linearly correlate with the taper degree in the pull-out test, whereas a more asymptotic performance was found in the knock-out test.

Discussion

In this investigation, we used uni-axial pull-out tests and knock-out tests. In general, both tests cannot accurately reproduce all oral factors that may dislodge a crown fixed onto a dental implant abutment. However, the advantage of the uni-axial test is that the impact of individual abutment or

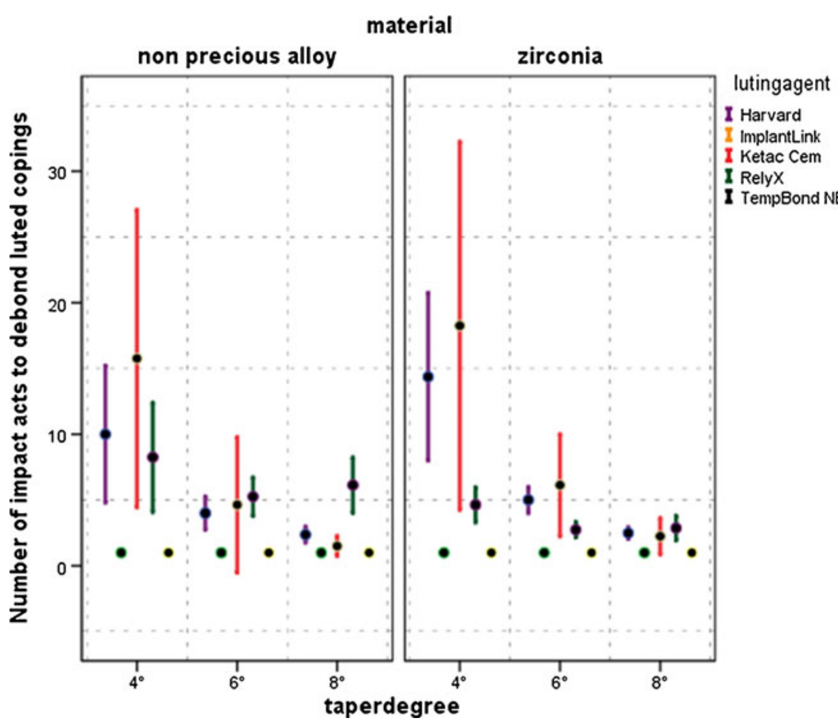


Fig. 11 Knock-out test of CoCr copings and zirconia copings (high-impact intensity of CORONAflex device; see: "Materials and methods"). Statistics: please see Table 7

Table 7 Univariate variance analysis: knock-out test (high-impact force application): zirconia and CoCr copings (see Fig. 11)

F value	Sig.
Main factor: luting agent; $F(6,330)=39.05$	0.0001
Main factor taper degree; $F(2, 334)=74.75$	0.0001
Main factor material; $F(1,335)=5.59$	0.019
Interaction luting agent × taper degree; $F(12,324)=13.39$	0.0001
Interaction luting agent × material; $F(6,330)=4.87$	0.0001
Interaction taper degree × material; $F(2,334)=0.81$	0.442
Interaction luting agent × taper degree × material; $F(12,324)=3.84$	0.155

Luting agents: Ketac Cem, Harvard Cement, Temp Bond NE, Implant Link, RelyX Unicem. Taper degree, 4°, 6°, 8°. Material of copings: CoCr-alloy, zirconia

copings factors on the retentiveness levels of cements can be studied. Such factors are

- The taper degree of an abutment
- The height of an abutment
- The roughness of a surface
- The surface texture (metal or ceramic)
- The fit of a crown on an abutment
- The type of cement
- The mixing ratio of a cement
- The cement layer thickness
- Thermal cycles
- And the type of force impulses: slowly or fast dislodging impulses

The influence of the taper degree, the height of the abutment, the impact of thermal cycles and surface roughness have been investigated by many authors [3, 5, 7, 18], who found decreasing retentiveness levels with increasing taper degrees (e.g. 4° to 8°). Most authors have proposed a linear relationship, and we could confirm the influence of the taper degree (the abutment height was constant for all specimens) on the level of retentiveness in our study (Figs. 7, 11, and 12). However, the influence of the taper degree was reduced with increasing taper degrees. Although 4°-abutments showed the highest retention force for all cements, the difference between 6°- and 8°-abutments was smaller or neglectable. The dependence of the retention force on the taper degree can only be shown for solidly setting cement types, such as glass ionomers, polycarboxylates, and zinc-oxide-phosphates or composites. Figures 7 and 12 show that particularly the retentiveness levels of provisional cements were not that much affected by the taper degree. Mixed TempBond NE contains oily liquids and Implantlink contains plastifiers, which allow the filler particles of the set cement to move when tensile forces are applied to the cement layer [6, 8]. All other cements used in our study more closely fixed their filler particles to the matrix after setting. These cements work more like a solid body rather than a highly viscous liquid as provisional cements do. This liquid-like behavior of provisional cements was enforced during thermal cycles, which may explain why both provisional cements had the lowest levels of retentiveness after thermal cycling. This liquid-like behavior of provisional cements may also explain the fact that the degree of

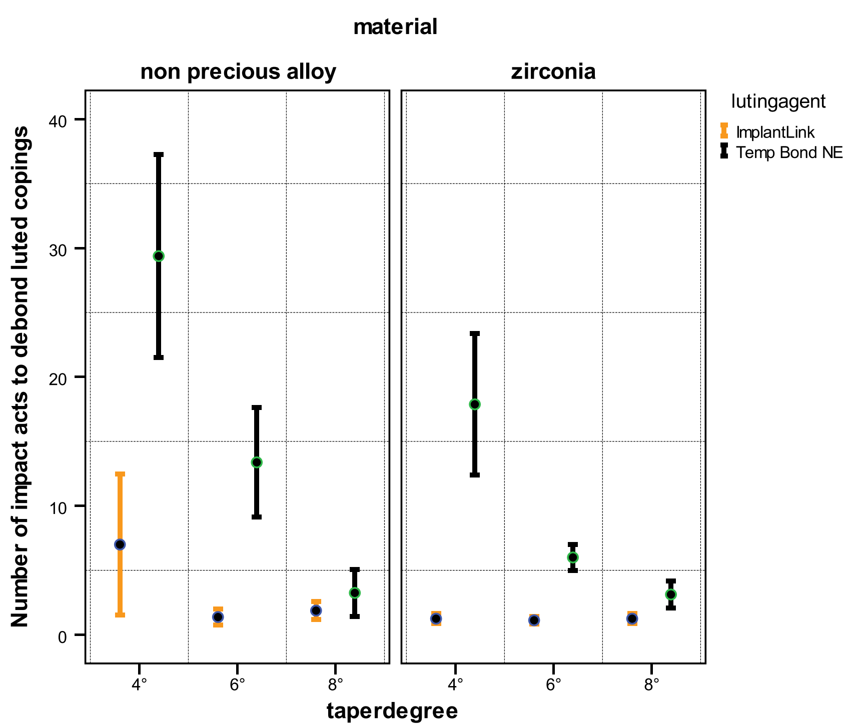


Fig. 12 Knock-out test of CoCr copings and zirconia copings (low-impact intensity of CORONAflex device; see: "Materials and methods"). Statistics: please see Table 8

Table 8 Univariate variance analysis: knock-out test (low-impact force application): zirconia and CoCr copings (see Fig. 12)

F value	Sig.
Main factor: luting agent; $F(1,95)=133.57$	0.0001
Main factor taper degree; $F(2, 94)=64.95$	0.0001
Main factor material; $F(1,95)=25.09$	0.0001
Interaction luting agent×taper degree; $F(2,94)=37.31$	0.0001
Interaction luting agent×material; $F(1,95)=5.85$	0.018
Interaction taper degree×material; $F(2,94)=7.87$	0.001
Interaction luting agent×taper degree×material; $F(2,94)=1.89$	0.157

Luting agents: Temp Bond NE, Implant Link. Taper degree, 4°, 6°, 8°. Material of copings: CoCr-alloy, zirconia

roughness of the inner surfaces of the copings only slightly increased the level of retentiveness of the more solid cement types. Even so, incorrect mixing ratios or higher liquid contents may cause unfavorable setting reactions; for instance, when filler particles do not become optimally fixed into the cement matrix. This problem occurred with polycarboxylates (Figs. 11 and 12) because the rather different behavior of this cement type was unexpected. Although their chemical composition is rather similar (particularly that of Aqualox and Carboco, which are produced by the same manufacturer), their levels of retentiveness differed. Generally, we found the highest levels of retentiveness for polycarboxylates, which was in concordance with the results of, for example, Mansor [17]. The reason for these high levels is that polycarboxylates can react with the oxides of the metal alloys of the abutments and the copings, therefore forming a chemical bond [8]. However, such bonding should also be possible for glass ionomers or self-adhesive cements. Therefore, it is more likely that polycarboxylates produce bigger agglomerates of filler particles during the setting process, which act similarly to a cotter bolt between coping and abutment (Danebrock, VOCO, personal communication, 2011). This explanation is strengthened by the fact that Aqualox showed the highest level of retentiveness. Aqualox contains freeze-dried polycarboxylate acid chains in its powder that become initiated by water addition. Because of a powder surplus (Fig. 9), the initiation reaction becomes so intense that big agglomerates of filler particles arise that work as cotter bolts between coping and abutment. Therefore, even if cements seem to be nearly identical with regard to their chemical components, statements about the level of retentiveness of a particular cement brand cannot be automatically universalized. We had to reject the hypothesis that cements of the matching “chemical” group, e.g. carboxylates, will have all equivalent retentive properties. Therefore, we have not compared the retention forces measured in different studies [3, 14, 17, 25].

All investigations have had the common problem of a high range of retention values and standard deviations [7, 17, 25]. The reason for this high range is, in our opinion, the differences in the thickness of the cement layer. We tried to achieve a constant layer thickness by using a standardized luting protocol. Cements were either mixed with an accurately weighted powder-to-liquid ratio [2] or with automatic mixing devices. A weight of 1.8 kg was applied to the luted copings for 10 min during setting. However, the layer thickness could not be checked after cementation without destruction of the specimens.

This study compared copings made of CoCr-alloy and zirconia. We hypothesized that the various surface textures and the different properties of metal alloys and zirconia may influence the level of retentiveness, and this hypotheses had to be rejected. Up to now, only alloy-based crowns or copings have been investigated. With the same type of cement, both coping materials showed no significant level of retentiveness, independent of the test used, i.e., a slow-acting pull-out test or a fast-acting knock-out test. As a next step, abutments made of zirconia should be investigated with luted zirconia copings.

Both the pull-out test and the knock-out test design represent special clinical situations only. Slow-acting dislodging forces may occur with sticky food bolus, and the knock-out test simulates the situation when a crown should be removed from an abutment for inspection. But other clinical situations of dislodgments are not taken into account. Therefore, this investigation cannot recommend a particular cement or type of cement for luting metal-alloy or zirconia copings on titanium abutments. A perfect luting agent for implant restorations should offer the opportunity for dentists to vary the level of retentiveness of the cement depending on the clinical situation. In some cases, retrievability is indicated, while, in other clinical situations, a permanent fixation will be the best option. Furthermore, a perfect implant luting agent should be easily and completely removable from the abutment or restoration surface [23]. Additionally, dental implant cements should contain components that reduce plaque accumulation and prevent periimplantitis. However, this requirement is not fulfilled by any of today’s cements.

Conflict of interest The authors declare that they have no conflict of interest.

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