Acta Odontologica Scandinavica. 2016; 74: 108–114

informa
healthcare

ORIGINAL ARTICLE

Tensile strength of Ni-Cr copings subjected to inner surface sandblasting using different cementing agents: An *in vitro* study

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Abstract

Objectives. To evaluate the effect of thermal cycling and inner surface treatment with aluminum oxide at different granulations on the tensile strength of Ni-Cr copings cemented with different cementing agents. ***Materials and methods.*** Ninety-six metal copings were manufactured and divided into two groups: before and after thermal cycling ($n = 48$). The copings of both groups were internally treated by sandblasting with aluminum oxide particles of 100 ($n = 24$) and 320 ($n = 24$) mesh. The copings were cemented on previously manufactured metal cores using zinc phosphate ($n = 8$), conventional glass ionomer (CGIC) ($n = 8$) and resin-modified glass ionomer (RMGIC) ($n = 8$) cements. The tensile strength before and after thermal cycling was then determined (Newtons). ***Results.*** The tensile strength before and after thermal cycling was significantly higher in copings cemented with RMGIC compared to CGIC ($p < 0.05$) and was similar to that for zinc phosphate ($p > 0.05$). Thermal cycling and sandblasting of the inner surface of the metal copings with different granulations did not influence retention ($p > 0.05$). ***Conclusions.*** Zinc phosphate cements and RMGIC showed similar retention. Additionally, the retention of the cements was not influenced by either thermal cycling or the particle size of the aluminum oxide.

Key Words: *Tensile strength, metal coping, dental cements, thermal cycling*

Introduction

Indirect restorations are recommended in oral rehabilitation when there is a significant loss of tooth structure [1]. In some clinical procedures, crowns with metal sub-structures are used to replace tooth crowns previously destroyed by pathological or physiological processes or injury. Thus, researchers have studied different ways to increase the retentiveness of these indirect restorations [2–6].

In this context, prosthesis retention is a function not only of the mechanical and biological properties of the cementation agent [6–9] but also of the characteristics of the dental preparation (such as the taper, height and surface texture) where the fixed partial denture is cemented [7,9–11]. Moreover, the larger the convergence angles of the tooth preparation, the lower the resistance to lateral load [12].

The inner surface texture of the copings is also an important factor in the retention of fixed partial dentures [3,4,8]. However, studies evaluating the influence of the size of aluminum oxide particles on the tensile strength of metal copings are uncommon in the literature.

Cement is considered the weakest component of the system, constituted by the tooth, cement and coping, and the choice of cementing agent is determined by the biological and functional characteristics of the clinical case. The cement must form a barrier to bacterial microleakage between the tooth and the restoration and must hold the two surfaces together by a mechanical and/or chemical bond [9,13,14]. Furthermore, the strength of the cementing agents may be altered by improper handling of the cement or solubility and temperature variations.

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(Received 22 July 2014; accepted 8 May 2015)

ISSN 0001-6357 print/ISSN 1502-3850 online
DOI: 10.3109/00016357.2015.1050602

Zinc phosphate cement was originally introduced to dentistry in 1877 [8], and its adhesion occurs by mechanical imbrication, generated by roughness on the substrate and on the inner surface of the copings [2,8,9]. Although zinc phosphate cement has disadvantages, such as a lack of chemical adhesion, solubility and disintegration, it is still used with clinical success in the cementing of cast restorations due to its mechanical strength, low film thickness and low cost [8].

To achieve a better retention of fixed partial dentures, cements with adhesive properties, such as conventional glass ionomer cement (CGIC) and resin-modified glass ionomer cement (RMGIC), have been developed [2,5,8]. The retention provided by the adhesive technique with agents containing resin is 3-times greater than that obtained with CGIC [8]. However, the retention of these materials on metal sub-structures and cast metal cores is compromised, being restricted to mechanical imbrication with surface roughness [3,15]. The retention of these agents can be improved by the application of chemical components (metal primers) that improve the bond strength of the cement, rendering the metal surface more compatible with the constituents of resin-modified cements [3,16,17].

Assuming that the retention of indirect restorations can also be influenced by the cementing agent [11,18] and the inner surface roughness of the copings [3,4], this study aimed to evaluate the tensile strength of Ni-Cr copings cemented with different cements (zinc phosphate and conventional and resin-modified glass ionomer), combined with an inner surface treatment of the metal copings with aluminum oxide at different granulations (100- and 320-mesh), before and after thermal cycling.

Materials and methods

Manufacture of metal cores

Ninety-six Ni-Cr metal cores were obtained from a master model composed of stainless steel and were divided into groups, as shown in Table I. This master model presented a crown preparation with a 4°20’ total axial wall taper, a height of 8.28 mm and a chamfer finish line. The occlusal surface was flat with a diameter of 5.58 mm and a cervical shoulder of 9.16 mm.

Acrylic resin custom trays were manufactured and the master model was duplicated using condensation silicone impression material (Optosil®/Xantopren®, Heraeus Kulzer, Germany). The molding process was conducted with the aid of a surveyor to standardize the process of molding and to provide a uniform mold with reduced distortion.

Molten modeling wax was poured inside the mold, thus producing replicas of the dies (representing metal cores). The replicas were then cast by the conventional method, using an oxygen-gas flame with subsequent injection of the Ni-Cr dental alloy (Verabond II, AAlba Dent, Cordelia, CA) into the mold by centrifugation.

Table I. Experimental groups.

Moment of thermal cycling (*n*)	Aluminum oxide particles (*n*)	Cementing agent		
		Zinc Phosphate (*n*)	CGIC[a] (*n*)	RMGIC[b] (*n*)
Before (48)	100 mesh (24)	8	8	8
	320 mesh (24)	8	8	8
After (48)	100 mesh (24)	8	8	8
	320 mesh (24)	8	8	8

[a] Conventional glass ionomer cement.
[b] Resin-modified glass ionomer cement.

Manufacture of Ni-Cr copings

Plaster dies were produced from the cast metal cores to obtain the Ni-Cr copings. Initially, these metal cores were embedded in a plastic ring with chemically activated resin and were then molded with condensation silicone impression material (Optosil®/Xantopren®). The plaster dies were obtained and the copings were waxed. For this, a capsule-matrix was used, surpassing the height of the plaster dies by 1 mm, to standardize the thickness of the wax patterns (Figure 1A). Wax patterns were cast with Ni-Cr dental alloy in a Discovery Plasma Ar-arc vacuum-pressure casting machine (E.D.G. Equipamentos e controles Ltda., São Carlos, SP, Brazil). The castings were divested immediately after cooling to room temperature (Figure 1B).

After casting, the 96 obtained copings were divided into two large groups, and the inner surfaces of these copings were sandblasted with 100- and 320-mesh aluminum oxide particles, respectively (Table I), under a pressure of 80 lib/pol^2 (5.62 kgf/cm^2). The surfaces were examined for the existence of defects and nodules. The inner surfaces of the copings sandblasted with aluminum oxide were analyzed using a scanning electron microscope (SEM) (Zeiss, EVO 50, Cambridge, UK) at 500× and 5000× magnification.

Cementing procedure

The copings were cemented (Figure 1C) using the following materials: zinc phosphate cement (SS White, Rio de Janeiro, RJ, Brazil), conventional glass ionomer cement (CGIC) (Ketac Cem Easymix, 3M ESPE, Seefeld, Germany) and resin-modified glass ionomer cement (RMGIC) (Rely X luting 2, 3M ESPE).

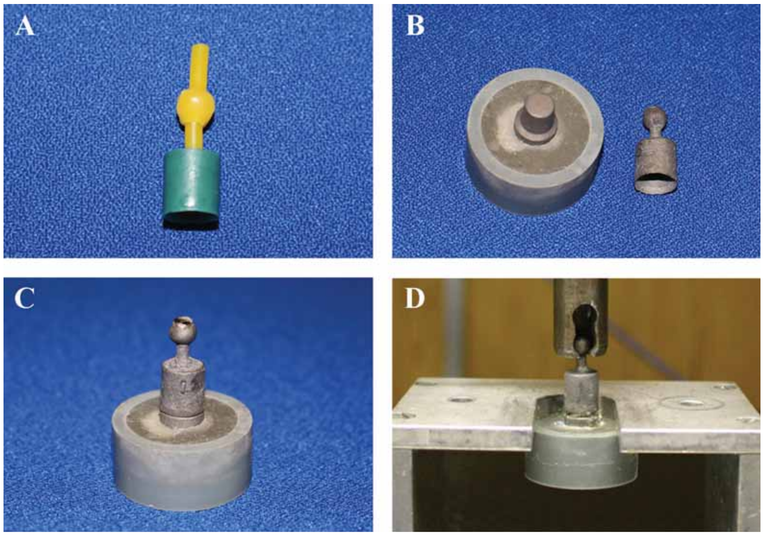

Figure 1. Specimen preparation. Wax patter of the coping (A); cast metal core and its respective coping (B); cementation (C) and adaptation in a universal testing machine (D).

The cements were applied following the manufacturers' recommendations. To avoid vertical discrepancies among the copings, as described by Eames et al. [19], a metal device (5 kg) attached to the top of the mobile rod of a modified surveyor was used to maintain constant pressure until the final setting of the cement was accomplished [20].

Tensile strength test of the specimens

Twenty-four hours after cementation, tensile strength tests were performed for 48 copings (24 copings sandblasted with 100-mesh aluminum oxide particles and 24 copings with 320-mesh aluminum oxide particles) using a universal testing machine (EMIC, São José dos Pinhais, PR, Brazil). The tensile tests were performed at a crosshead speed of 2.0 mm/min with a 50-kN (5000 kgf) load cell. The upper end of the coping was adapted in the upper claw of the testing machine and the plastic matrix was embedded in the bottom claw (Figure 1D). The load required to break the bond between the coping and the standard model was recorded in Newtons (N).

Thermal cycling

The 48 remaining copings were cemented in their respective metal cores and were subjected to 2000 thermal cycles (Cycling machine MSCT-3, São Carlos, SP, Brazil) at temperatures ranging between 5–55°C to simulate the temperature variations experienced by prosthetic elements in the oral cavity. Each cycle lasted for 3 min. During the first minute, the specimens were immersed in water at 5°C; in the second minute, they were immersed in water at room temperature (37°C); and to complete the cycle, the specimens were immersed in water at 55°C. After thermal cycling, the copings were tested using the tensile strength test, as described previously.

Statistical analysis

A pilot study to determine the sample size of each group was conducted using the tensile strength data for the first five Ni-Cr copings of the first group evaluated (sandblasting with 100-mesh aluminum oxide particles and cementing with zinc phosphate). The sample size of the study was calculated assuming a significance level of 5% ($\alpha < 0.05$) and a statistical power of 95%. According to this analysis, the estimated sample size was eight in each group ($n = 8$). The Kolmogorov–Smirnov test revealed a normal distribution of results. Thus, two-way ANOVA followed by Tukey's test was applied to evaluate differences between the various groups. All analyses were performed with the Statistical Package for Social Sciences (version 17.0; SPSS Inc., Chicago, IL).

Results

The mean values and standard deviations of the tensile strength of the samples cemented with different agents, before and after thermal cycling and sandblasting of the inner surface, are reported in Tables II and III, respectively.

The highest tensile strength values were observed for the copings cemented with RMGIC. Before thermal cycling, the tensile strength of the copings cemented with RMGIC was similar to that of the zinc phosphate cement ($p > 0.05$), but significantly higher than that for the conventional glass ionomer ($p < 0.05$), when the samples were sandblasted with 100-mesh (1675.89 ± 296.14) and 320-mesh (1586.16 ± 394.49) particles (Table II, Figure 2). After thermal cycling, the mean tensile strength

Table II. Mean and standard deviation (SD) with Tukey's test results of the tensile strength (N) of Ni-Cr copings cemented with zinc phosphate cement (G1), conventional glass ionomer cement – CGIC (G2) and resin-modified glass ionomer cement – RMGIC (G3), before and after thermal cycling.

	Cement		
	Zinc phosphate Mean (SD)	CGIC Mean (SD)	RMGIC Mean (SD)
Before thermal cycling			
100 mesh	1380.89 (212.73)^{aA}	832.98 (367.86)^{bB}	1675.89 (296.14)^{cA}
320 mesh	1346.59 (250.32)^{aA}	572.66 (276.45)^{bB}	1586.16 (394.49)^{cA}
After thermal cycling			
100 mesh	971.90 (173.62)^{aAB}	597.80 (341.73)^{bA}	1378.71 (328.44)^{cB}
320 mesh	1119.99 (214.81)^{aA}	566.62 (209.70)^{bB}	1423.16 (269.25)^{cA}

Different lower case (columns) and capital (rows) letters indicate significant differences ($p < 0.05$).

Table III. Mean and standard deviation (SD) with Tukey's test results of the tensile strength (N) of Ni-Cr copings cemented with zinc phosphate cement (G1), conventional glass ionomer cement – CGIC (G2) and resin-modified glass ionomer cement – RMGIC (G3), according to the particle size of the aluminum oxide.

	Cement		
	Zinc phosphate Mean (SD)	CGIC Mean (SD)	RMGIC Mean (SD)
100 mesh			
Before	1380.89 (212.73)^{a}	832.98 (367.86)^{b}	1675.89 (296.14)^{c}
After	971.90 (173.62)^{a}	597.80 (341.73)^{b}	1378.71 (328.44)^{c}
320 mesh			
Before	1346.59 (250.32)^{a}	572.66 (276.45)^{b}	1586.16 (394.49)^{c}
After	1119.99 (214.81)^{a}	566.62 (209.70)^{b}	1423.16 (269.25)^{c}

Different lower case letters (columns) indicate significant differences ($p < 0.05$).

decreased for all conditions; however, these decreases were not statistically significant ($p > 0.05$, Table III).

The size of the aluminum oxide particles (100- or 320-mesh) did not affect the tensile strength of the copings before or after thermal cycling ($p > 0.05$, Tables II and III, Figure 2).

The appearances of the inner surfaces of the Ni-Cr copings after sandblasting with 100- and 320-mesh aluminum oxide particles were investigated by SEM (Figure 3). The images showed similarities in the surface roughness profile, regardless of the amount of sandblasting steps (1 or 2) or the size of the aluminum oxide particles (100- or 320-mesh).

Discussion

The retention of a fixed prosthesis is very important for clinical success and, thus, it is necessary, among other requirements, to evaluate the qualities of a cementing agent [68] and of inner surface treatments for copings due to their ability to facilitate the mechanical retention of the cement [3–8]. In this context, tensile strength tests are often used, based on the load required for the removal of crowns during the movement of traction.

Research has shown that zinc phosphate cement can indefinitely resist the most varied forces during chewing movements, even though it exhibits some negative properties, such as high solubility and a deficiency in marginal sealing [8,9,21]. The clinical performance of zinc phosphate cement is one of the reasons for its use in the present study, where it was employed for comparison with conventional and resin-modified glass ionomer cements, which are also frequently used in the cementation of crowns.

In this context, the present study simulated a clinical situation in which a crown with a metal sub-structure was cemented onto a cast metal core to determine which cement has the best tensile strength, while evaluating the influence of thermal cycling and inner

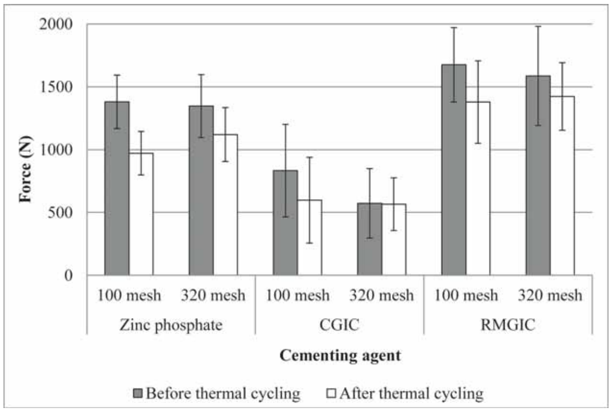

Figure 2. Mean and standard deviation (SD) of the tensile strength (N) of Ni-Cr copings cemented with various cement agents and subjected to sandblasting with aluminum oxide particles, before and after thermal cycling.

surface treatments of Ni-Cr copings with aluminum oxide particles of different granulations.

In general, the results for the Ni-Cr copings before thermal cycling showed a better retention for RMGIC when compared to CGIC ($p > 0.05$) and a similar retention for zinc phosphate cement ($p > 0.05$). These results support a variety of studies that have reported the superiority of RMGIC compared to CGIC [5,10,18,22]. However, in this study, RMGIC was found to have a tensile strength similar to that of zinc phosphate cement, thus differing from some studies that have reported higher tensile strengths for RMGIC [6,10,18]. This difference is explained in most studies by the simulation of clinical conditions in which a crown is cemented onto a natural tooth; dentin conditioning followed by penetration, impregnation and adhesive polymerization determines the formation of the hybrid layer, which is responsible for the higher tensile strength achieved for crowns cemented with RMGIC or resin cements [5,6,23]. In cases where cementation occurs between a metal sub-structure and a cast metal core, the retention of these cements is considerably reduced and, in these cases, the use of metal primers to better match the metal surface of the copings with resin-based cement agents is justified, significantly improving the bond strength [3,11,24].

After thermal cycling, the mean tensile strength decreased, as reported in the literature, but no significant differences were observed ($p > 0.05$, Table III). According to these results, thermal cycling (2000 cycles) does not seem to influence the tensile strength of the studied cements. These results agree with the findings of Kern and Wegner [25], who reported that, after 37,500 thermal cycles, no significant effect on retention loss was observed in zirconia crowns with a silica-based inner surface treatment.

One interesting finding of this study was a considerable reduction in the retention of the zinc phosphate cement, particularly in the copings sandblasted with 100-mesh aluminum oxide particles. Before thermal cycling, the tensile strength of the copings cemented with zinc phosphate and CGIC showed a significant difference (different capital letters), but after thermal cycling, the tensile strengths were similar (equal capital letters) (Table II). This finding may be due to the constant contact of the cement with the ambient moisture, which generates solubilization and degradation of the cement and, consequently, a considerable reduction in its tensile strength [26]. Thus, the mechanical imbrication of the zinc phosphate cement achieved by the inner surface roughness of the copings is an important factor in the retention of prostheses [9,21].

The mean tensile strength of the CGIC was the lowest for all situations and, based on these results, the CGIC may not be suitable for the cementation of crowns with metal sub-structures on cast metal cores. This process can cause long-term damage, particularly in areas of excessive stress upon mastication, although there are clinical advantages to the use of this agent when cemented onto the tooth structure, such as chemical adhesion, long-term fluoride release and a low coefficient of thermal expansion [9,21,27].

Pavanelli and Araujo [20] found the tensile strength of capsules cemented onto metal cores to be very high, ranging between 1900 N and 3113.25 N. These tensile strengths are considerably higher than those found in this study (566.62–1675.89 N) and can be explained by the presence of grooves and relief in the capsules. Thus, we suggest a standardization of methodology to allow for a comparison of parameters that are more homogeneous and to achieve greater reliability and scientific validity in the results.

Various surface treatments are available for enhancing cement retention; these aim to increase the strength and/or mechanical imbrication between the inner surface of the crown and the cement [3,4]. This study evaluated the influence of sandblasting with 100- and 320-mesh aluminum oxide particles on retention and it was found that the use of such aluminum oxide particles (100- or 320-mesh) resulted in the same retention efficiency ($p > 0.05$) in all cases studied (before and after thermal cycling). Although sandblasting with aluminum oxide particles increased the surface roughness (Figure 3), favoring the mechanical imbrication of the cementing agent, the results of this study showed that this micro-retention was not sufficient to enhance the overall retention.

Conversely, Castillo-Oyagüe et al. [28] observed a surface-smoothing effect in cast Ni-Cr-Ti structures after sandblasting (125-μm aluminum oxide particles). According to these authors, large particles of aluminum oxide may be associated with an abrasive effect on cast structures. Thus, sandblasting with large particles can affect the substrate texture and reduce retention, despite the absence of a significant

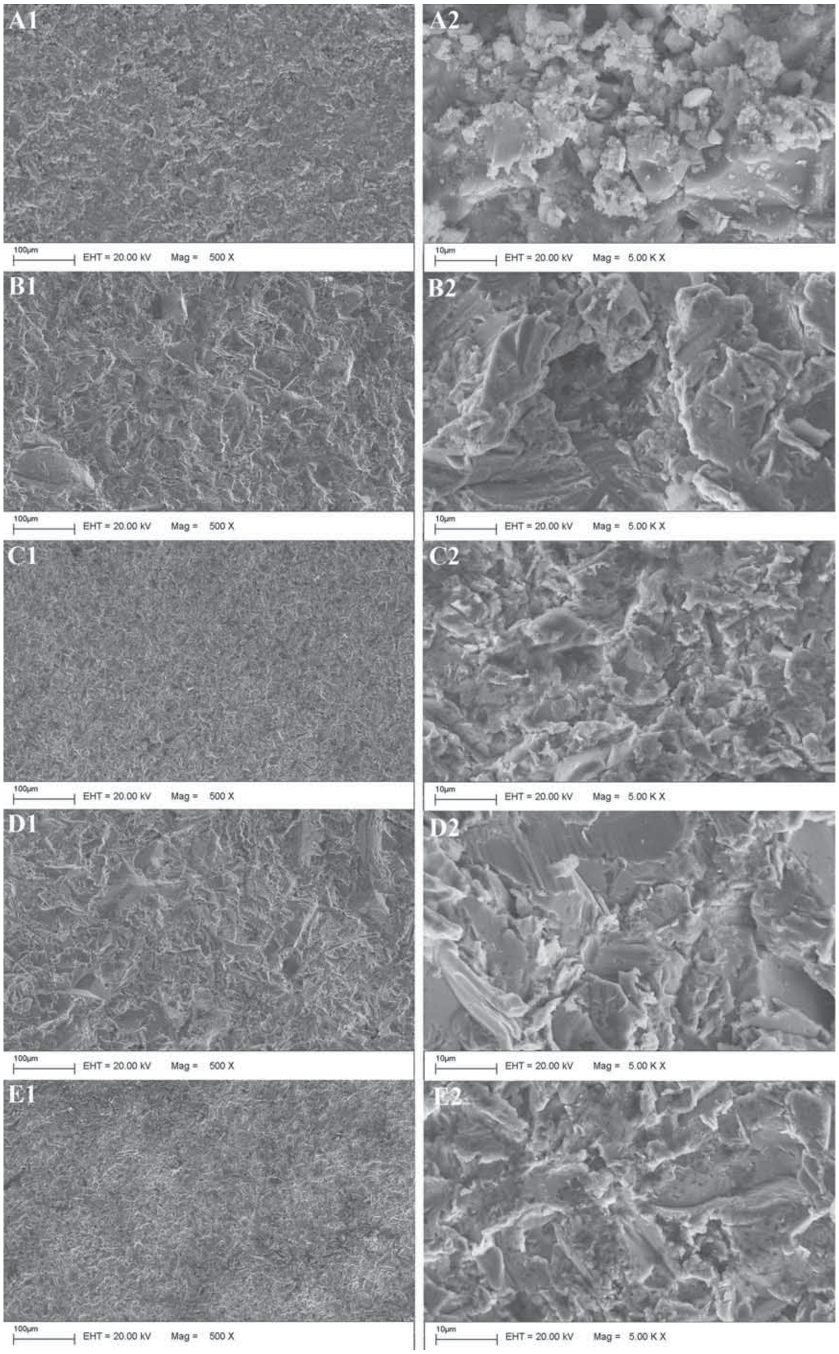

Figure 3. Scanning electron microscopy. Control group (A); group submitted to one sandblasting step with 100-mesh (B) and 320-mesh (C) aluminum oxide particles; group submitted to two sandblasting steps with 100-mesh (D) and 320-mesh (E) aluminum oxide particles. 500× (1) and 5000× (2) magnification.

difference for the 100- and 320-mesh aluminum oxide particles in this study.

Within the limitations of this study, the results indicate that the zinc phosphate cement and RMGIC have the same retentive efficacy for cementing Ni-Cr copings onto cast metal cores; this retention was not affected by thermal cycling or by sandblasting the inner surface of the metal copings with different particle size of aluminum oxide.

Acknowledgments

This investigation was supported by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

***Declaration of interest*:** The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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