Fracture Resistance and Strain Analysis of Zirconia Copings With Vertical Knife Edge and Three Horizontal Finish Line Designs; Chamfer, Deep Chamfer and Shoulder With Two Cementation Techniques

Resistência à fratura e análise de deformação de copings de zircônia com término cervical em lâmina de faca e três términos horizontais; chanfro, chanfro largo e ombro com duas técnicas de cimentação

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ABSTRACT

Objective: The purpose of this in vitro study is to evaluate the effect of four finish line configurations and two cement types on the fracture resistance of zirconia copings. **Material and Methods:** Forty yttrium tetragonal zirconia polycrystals copings were manufactured on epoxy resin dies with four preparation designs: knife edge, chamfer, deep chamfer 0.5, 1 mm and shoulder 1 mm. The copings were cemented with two cement types (glass ionomer and resin cement); (n = 5). Two strain gauges were attached on each coping before they were vertically loaded till fracture with a universal testing machine. Data were analyzed by 2-way analysis of variance ANOVA (p < .05). Fractured specimens were examined for mode of failure with digital microscope. **Results:** Knife edge showed the highest mean fracture resistance (987.04 ± 94.18) followed by Chamfer (883.28 ± 205.42) followed by Shoulder (828.64 ± 227.79) and finally Deep chamfer finish line (767.66 ± 207.09) with no statistically significant difference. Resin cemented copings had higher mean Fracture resistance (911.76 ± 167.95) than glass ionomer cemented copings (821.55 ± 224.24) with no statistically significant difference. Knife edge had the highest strain mean values on the buccal (374.04 ± 195.43) and lingual (235.80 ± 103.46) surface. Shoulder finish line showed the lowest mean strain values on the buccal (127.47 ± 40.32) and lingual (68.35 ± 80.68) with no statistically significant difference. Resin

RESUMO

Objetivo: O objetivo deste estudo in vitro é avaliar o efeito de quatro configurações de términos cervicais e dois tipos de cimentos na resistência à fratura de copings de zircônia. **Material e Métodos:** Quarenta copings de zircônia tetragonal policristalina estabilizada por ítrio foram confeccionados em matrizes de resina epóxi com quatro tipos de términos cervicais: lâmina de faca, chanfro, chanfro largo 0,5, 1 mm e ombro 1 mm. Os copings foram cimentados com dois tipos de cimento (ionômero de vidro e cimento resinoso); (n = 5). Dois extensômetros foram fixados em cada coping antes de serem carregados verticalmente até a fratura com uma máquina de teste universal. Os dados foram analisados por análise de variância ANOVA 2 fatores (p < 0,05). Os espécimes fraturados foram examinados quanto ao modo de falha com microscópio digital. **Resultados:** A Lâmina de faca apresentou a maior média de resistência à fratura (987,04 ± 94,18) seguida pelo Chanfro (883,28 ± 205,42), pelo Ombro (828,64 ± 227,79) e finalmente o Chanfro largo (767,66 ± 207,09), sem diferença estatisticamente significativa. Os copings cimentados com cimento resinoso apresentaram maior média de resistência à fratura (911,76 ± 167,95) em relação aos copings cimentados com ionômero de vidro (821,55 ± 224,24), sem diferença estatisticamente significativa. A lâmina de faca apresentou os maiores valores médios de deformação na superfície vestibular (374,04 ± 195,43) e lingual (235,80 ± 103,46). O término em ombro apresentou os menores valores médios de deformação na superfície vestibular (127,47 ± 40,32) e lingual (68,35 ± 80,68), sem diferença estatisticamente significativa. Os copings cimentados com resina apresentaram maiores

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cemented copings had higher buccal (295.05 ± 167.92) and lingual (197.38 ± 99.85) mean strain values than glass ionomer copings (149.14 ± 60.94) and (90.27 ± 55.62) with no statistically significant difference. **Conclusion:** Vertical knife edge finish line is a promising alternative and either adhesive or conventional cementation can be used with zirconia copings.

KEYWORDS

Cementation; Flexural strength; Prosthodontics; Tooth preparation; Zirconium.

valores médios de deformação na superfície vestibular (295,05 ± 167,92) e lingual (197,38 ± 99,85) do que os copings cimentados com ionômero de vidro (149,14 ± 60,94) e (90,27 ± 55,62), sem diferença estatisticamente significativa. **Conclusão:** O término cervical em lâmina de faca é uma alternativa promissora e a cimentação adesiva ou convencional pode ser usada na cimentação de copings de zircônia.

PALAVRAS-CHAVE

Cimentação; Resistência à flexão; Prostodontia; Preparo do dente; Zircônio.

INTRODUCTION

As all-ceramic restorations when placed in the posterior region, had a history of being prone to fracture, strong ceramic core materials have been developed to support the weaker veneering ceramic materials [1,2]. Zirconia (ZrO_2) has been introduced as a promising metal-free core structure for fixed prostheses due to its superior physical and mechanical properties, chemical stability, and excellent biocompatibility [3]. The material's high flexural strength of 900 megapascals (MPa) to 1200 MPa [4] is due to its unique property to stop the crack propagation "self healing", the tensile stress generated by the crack induces a change from a tetragonal T configuration to a monoclinic M configuration with localized volume increase of 3% to 5%. The energy is dissipated in the T-M transformation and stops the further advancement of the crack and increase the resistance to further crack propagation [4-10]. The rapid diversification in equipments and materials available for fabrication of computer-aided design/computer-aided manufacturing (CAD-CAM) prostheses along with an increase in the availability of dental laboratory processed CAD-CAM restorations is driving the use of ZrO_2 copings and framework materials. The relatively high stiffness and good mechanical reliability of partially stabilized ZrO_2 allows for thinner core layers, longer bridge spans, and the use of all-ceramic fixed partial dentures (FPDs) in posterior locations [11,12]. Modern adhesive technologies and ceramic materials with enhanced fracture toughness may facilitate the development of minimally invasive preparation designs which help preventing tooth weakening and pulp irritation [13,14]. When ZrO_2 was introduced, its fabrication guidelines were copied from metal ceramic systems [15]. Recommended values for cervical finish line varies from 0.5 to 1.2 mm deep chamfer or shoulder with rounded internal angle [16-20]. Tooth preparations without a defined finish line may be termed vertical preparations as opposed to horizontal ones [21]. The knife edge (KNE) finish line is considered the most conservative for sound tooth structure [19], its most common indications are periodontally involved teeth, [22] endodontically treated teeth, vital teeth in young individuals, and teeth affected by caries at the cervical third of the clinical crown [23]. The concept of minimally invasive dentistry and the superior mechanical properties of ZrO_2 allow clinicians to reconsider preparation guidelines such as reducing the coping thickness from 0.5 mm to 0.3 mm and changing finish line preparations from shoulder to chamfer or even KNE margins [24,25]. ZrO_2 restorations have high fracture resistance FR and can be cemented with conventional methods recommended by the manufacturers [26]. However, resin bonding between a dental substrate and a restoration

is advocated for improved retention, marginal adaptation, and inhibition of secondary caries [27,28]. On the other hands polycrystalline ceramics lack the ability to be etched thus compromizing the bond strength with cements [29]. To date, combined surface treatment with airborne particle abrasion (50 μm alumina particle size and maximum 2.5 bar pressure) and a specific adhesive monomer with a hydrophobic phosphate monomer have proved reliable for bonding to ZrO_2 ceramics [30-32].

There's evidence in the literature that the strength of the ceramic restoration is increased when bonded to the available tooth tissue [33]. Various techniques have been used to evaluate the stress and strain state in dental structures, including holographic interferometry, two- and three-dimensional photoelasticity, finite element analysis and strain gauge techniques [34-37]. Regarding the behavior of restored teeth under a functional load, stress was found to be concentrated at the cervical site [38]. Such localized stress concentrations are probably the initial sites of cement failure [39].

The purpose of this study was to evaluate how finish line preparations, and different cementation techniques influenced the resulting strain and fracture resistance of in vitro zirconia copings. This study tested a twofold null hypothesis, that neither the the finish line design nor the cement type will affect the fracture resistance of cemented ZrO_2 copings.

MATERIAL AND METHODS

Dies fabrication:

Four master stainless steel dies were milled. They all had the same dimensions of 5.5 mm crown height, 8mm gingival diameter, 6 degrees taper [40] except of different finish line configuration; [41] knife edge finish line (KNE), chamfer finish line with 0.5 mm thickness (CH), deep chamfer finish line with 1 mm thickness (DCH) and shoulder finish line with 1 mm

thickness (S). A 45° occlusal bevel was made to allow core orientation and act as antirotational feature and wide base was fabricated to the master dies for stability purposes (Figure 1). Each die was mounted with its long axis perpendicular to the top surface of a 17mm diameter plastic mold filled with polymethyl methacrylate polymer cold cure material (Acrostone, Cold cure, Cairo, Egypt) using a precision surveyor (Paraflex, Bego, Bremen, Germany). An addition curing vinyl polysiloxane duplicating material (Dupliflex, Protechno, Girona, Spain) was used for impression taking of each master die, the impressions were then poured with Epoxy resin (Kemapoxy 150 transparent, CMB, Cairo, Egypt) [40] to fabricate 40 identical resin dies (N = 40). The resin dies were allowed to polymerize for 24 hours [42] at least before separating the dies from their impression.

Figure 1 - Schematic drawing of the master dies showing their finishline configuration and antirotational feature. a: Knife edge, b: Slight Chamfer (0.5 mm), c: Deep Chamfer (1 mm) and d: Shoulder (1 mm).

### Construction of zirconia copings:

Forty Zirconia copings were fabricated, ten for each finish line geometry (n = 10). Each resin die was scanned for its own Zirconia coping with the Cerec-3 infra-red camera, restorations were designed with the Inlab 3.88 software and finally milled with the InLab MC XL milling unit of the CEREC InLab CAD/CAM System (Cerec 3; Sirona Dental Systems GmbH, Bensheim, Germany). The coping thickness was adjusted according to average manufacturers' recommendations to be 0.5 mm occlusal and midaxial for all groups ending with the suitable margin according to the corresponding die's finish line and with a cement space of 35 μm [42]. The milled cores were sintered in high-temperature furnace Infire HTC speed sintering furnace (Cerec 3; Sirona

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Dental Systems GmbH, Bensheim, Germany) for 90 minutes at 1540 °C. After sintering process the copings were adjusted for perfect fit on their corresponding dies. The fitting surfaces of the copings of all groups were air abraded (Basic classic; Renfert GmbH, Hilzingen, Germany) with $100\mu m$ aluminium oxide (Al_2O_3) [43] at 2 bar from 10 mm and for 10 seconds [44].

Cementation and fracture resistance test:

Each finish line group was divided to two subgroups (n = 5) each, in the first subgroup the copings were cemented with glass ionomer cement (GC Fuji I, GC corporation, Tokyo, Japan) and the second subgroup was cemented with self adhesive dual cured resin cement (G-Cem, GC corporation, Tokyo, Japan), Both cements were activated and mixed for 10 seconds according to the manufacturer's instructions. The copings with extruded cement inside were then seated on the corresponding dies, excess cement was removed then the copings were loaded with a vertical load of 1kg for 10 minutes using a loading device to ensure complete seating. The margins of the resin cemented copings were light cured for 20 seconds on each side to ensure complete setting. Specimens were stored in distilled water at room temperature for 48 hours [41] before testing. Two strain gauges (BCD 300 A,KYOWA, Tokyo, Japan) of 1 mm length were bonded one on the buccal and one on the lingual surfaces of the coping 1mm above the margin (the beveled surface was named as the buccal one). To measure the FR of the ZrO_2 copings they were subjected to vertical loading in a universal testing machine (LRX-plus;LloydinstrumentsLtd.,   Fareham,UK) with a load cell of 5 Kilonewton (KN) till fracture occurred, The loading piston was centered on the coping's occlusal surface until catastrophic fracture occurred (Figure 2). The loading piston was a vertically movable rod with semispherical loading surface of 5 mm in diameter and speed of 0.5 mm/min [45]. The strain gauges lead wires were connected to a Strain Meter (BCD

300 A, KYOWA, Tokyo, Japan) to measure the strain induced in the samples from the moment of load application till failure occurred. The fragments of each specimen were retrieved and failed specimens were examined for assessment of mode of failure. Examination was done with digital microscope (Dino-Lite Pro II, Olympus, Tokyo, Japan). Statistical analysis of the obtained data was performed using SPSS version 20 (Statistical Package for Scientific Studies 19.0, IBM, Chicago, IL, USA) for Windows. Initially descriptive statistics for each group results were held. Fracture load data, in N, were analyzed with a 2-way analysis of variance (ANOVA) (p < .05) to assess the effect of finish line configuration and cement used over FR and strain.
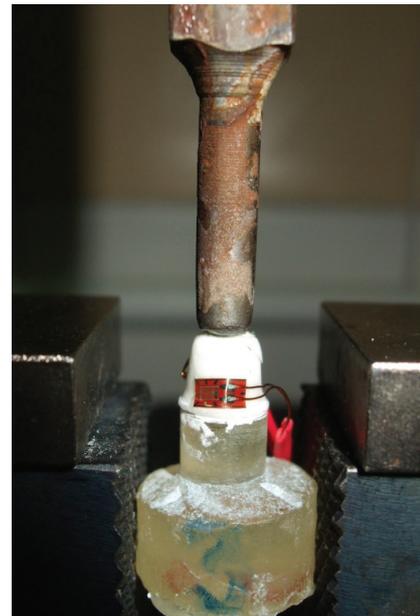
Figure 2 - Loading to fracture with the strain gauge cemented on the zirconia coping buccal and lingual.

RESULTS

Statistical analysis of FR results measured in Newton (N) and strain measured in ($\mu m/m$) for different finish line configurations and different cements were held.

-Descriptive statistics:

Fracture resistance:

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The data showed that KNE had the highest mean FR (987.04 ± 94.18) followed by CH finish line (883.28 ± 205.42) then S finish line (828.64 ± 227.79) and finally the DCH finish line (767.66 ± 207.09) (Figure 3). The data also showed that resin cemented copings (R) had higher mean FR (911.76 ± 167.95) than the glass ionomer (GI) cemented copings (821.55 ± 224.24) (Figure 3).
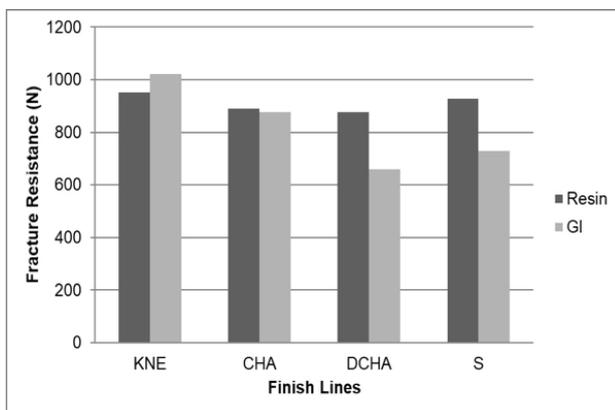
Figure 3 - A column chart of fracture resistance mean values for all finish line groups with different cement types.

Strain analysis:

The buccal strain for all finish lines was higher than the lingual. The data showed that regarding buccal strain the KNE had the highest mean strain values (374.04 ± 195.43) followed by CH (226.89 ± 96.60), DCH (159.96 ± 44.21) and finally S finish line (127.47 ± 40.32). Regarding lingual strain, KNE had the highest mean strain values (235.80 ± 103.46) followed by the DCH (137.51 ± 46.14), CH (133.63 and ± 71.35) and finally S finish line (68.35 ± 80.68). The data showed that resin cemented (R) copings had higher buccal and lingual mean strain values (295.05 ± 167.92) (197.38 ± 99.85) than glass ionomer cemented (GI) copings (149.14 ± 60.94) (90.27 ± 55.62). (Figure 4)
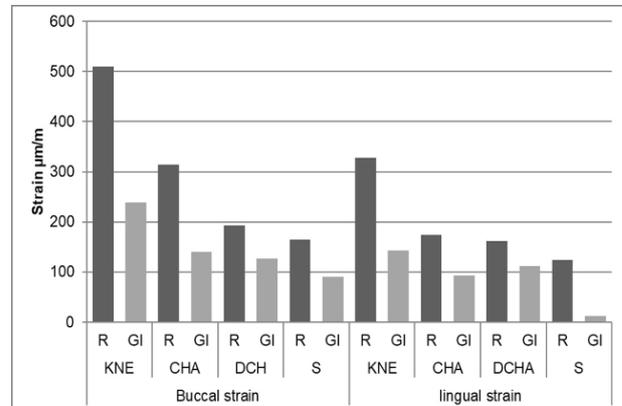
Figure 4 - A column chart of mean buccal and lingual strain values for different finish lines with different cements.

- Two-Way ANOVA:

Two-Way ANOVA for repeated measures was used to identify significance between groups. It showed that neither finish line configuration, nor cement type or any of their interactions had a statistically significant effect over FR of zirconia copings (Table I).

Table I - Two-Way ANOVA for the effect of finish line configurations, cement type and their interactions on the fracture resistance of TZP copings

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	490524.447a	7	70074.921	2.072	0.076
Intercept	30043635.56	1	30043635.6	888.356	0
Finish line	260140.891	3	86713.63	2.564	0.072
cement	81378.441	1	81378.441	2.406	0.131
Finish line * cement	149005.115	3	49668.372	1.469	0.242
Error	1082220.172	32	33819.38		
Total	31616380.18	40			
Corrected Total	1572744.619	39			

a. R Squared = .312 (Adjusted R Squared = .161)
*Significant at p < 0.05

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Two-Way ANOVA was used to identify significance between buccal and lingual strain within the same subjects, the buccal strain was higher than the lingual strain and the mean difference was statistically significant, the test also showed that different finish line types, different cements types and any of finish lines cements interactions had no effect on that significant difference.

Table II - Two-Way ANOVA for repeated measures showing the effect of finish lines, cements and their interactions on the buccal and lingual strain

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Strain	122514.466	1	122514.466	23.198	0.00*
strain * finishline	36517.346	3	12172.449	2.305	0.096
strain * cement	7529.916	1	7529.916	1.426	0.241
strain * finishline * cement	14816.687	3	4938.896	0.935	0.435
Error(strain)	169000.391	32	5281.262		

*Significant at p < 0.05

Mode of failure:

All specimens showed cohesive failure of the zirconia coping (100%) (Table III). The (R) copings showed a predominant type of cohesive failure of the epoxy resin die (90%) and adhesive failure btween the cement and the zirconia in (75%) of the samples (Figure 5). The (GI) copings showed a predominant type of mixed adhesive failure of the cement with the epoxy resin die and the internal surface of zirconia copings (65%). while none of the specimens showed cohesive failure of the die (0%) (Figure 6).
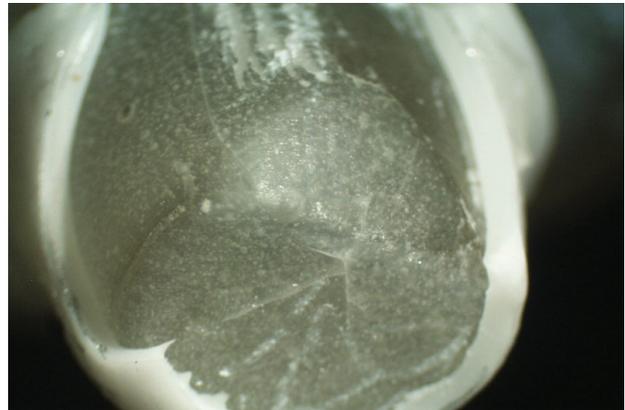
Figure 5 - Stereomicroscopic images of failed resin cemented zirconia copings showing the cracked die and adherent resin cement.

Figure 6 - Stereomicroscopic images of failed conventionally cemented zirconia copings showing the mixed adhesive failure.

Table III - Number of specimens and percentage (%) of each failure type in the two cement groups

	Cohesive failure		Adhesive failure of cement		
	Coping	Die	With the die	With the coping	Mixed
R Copings	20/20 (100%)	18/20 (90%)	0/20 (0%)	15/20 (75%)	5/20 (25%)
GI Copings	20/20 (100%)	0/20 (0%)	7/20 (35%)	0/20 (0%)	13/20 (65%)

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DISCUSSION

In this study the results support acceptance of the two fold null hypothesis that FR of ZrO_2 copings didn't differ with different finish line designs or cement types. The evolution in dental materials adhesive technologies have led to interest in Minimally Invasive Dentistry with maximum preservation of tooth structure [14]. So the purpose of this study was to evaluate whether high strength ZrO_2 core materials were suitable for different finish line preparations, and how changing the cement type influenced the resulting FR and strain analysis of in vitro prepared copings. The results of this study showed that regarding the effect of finish line on FR of ZrO_2 copings, the KNE finish line showed the highest mean FR followed by CH finish line then S and finally DCH finish line but the difference wasn't statistically significant. These results may be attributed to the amount of remaining supporting structure as the KNE and CH may have higher FR because of the increased amount of remaining supporting die structure. The results obtained from this study are in accordance with other studies, Beuer et al. [41] who reported insignificant higher FR of KNE finish line than S finish line which had higher mean FR than CH and DCH significantly. The favorable results of the KNE preparation was explained as when applied load on the coping was increased, the coping could slide down the axial wall of the die without being limited by the margin. This then resulted in a stress concentration on the occlusal surface of the coping [41] and this also may explain the reason why the GI cemented copings had higher FR than R copings in the KNE group only, as the glass ionomer may had facilitated this sliding movement of the coping over the finish line more than resin cement did. The favorable results of S finish line compared to DCH was explained that the occlusal forces were directed perpendicular on the circumferential S margin, and there was less stress concentration on

the axial walls compared to CH margin [41]. Reich et al. [13] reported a significant higher mean FR of ZrO_2 copings of KNE preparations over CH preparations. The results of this study showed higher FR of S over DCH preparations. This may be attributed to the increased cervical thickness of the S margin [38]. Mitov et al. [46] showed higher fracture resistance of monolithic zirconia crowns with KNE margin over CH and DCH although he did not recommend clinical application of KNE due to periodontal considerations. As a contradictive result; Skjold et al [25] concluded that ZrO_2 crowns made for a CH preparation fracture at significantly higher loads than similar crowns made for a slice preparation design but both at loads above normal mastication forces and referred that to increased thickness. A. Ahmadzadeh [2] and Jalalian et al. [42] compared the effect of DCH and S finish lines on the FR of ZrO_2 copings and found that the DCH preparation copings' FR was significantly higher than S preparation, and referred that to the rounded internal angle of DCH. Regarding the cement type; the results of this study showed that the R copings of all finish line groups -except KNE finish line- had higher mean FR than the GI copings and the difference showed no statistical significance. This may be attributed to strengthening effect of the resin cement by filling the pores and defects in the fitting surface of the coping and better force distribution [33]. As there is a difference in the modulus of elasticity between the two cements used, resin cement with modulus of elasticity closer to that of the die material and dentin is believed to transfer stress more effectively between the stiff coping and the supporting structure [13,39] and that was confirmed by the results of the mode of failure as most of the R copings showed abutment fracture or cracking suggesting direct load forces transfer to the underlying structure compared to GI copings. Casson et al. [29] explained the lower FR of GI copings by the glass ionomer cement's creep and interfacial

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delamination under vertical load. These results are in accordance with Tinschert et al.[3] Ernst et al.[26] Bindl et al. [24] and Rosentritt et al. [47] The strain measurements results of this study supported the FR results as the strain was higher in less invasive finish lines because thinner margins are more prone to flexion and displacement than thicker ones [48]. The higher buccal strain values over the lingual in all groups were attributed to the bevel which may have concentrated the stresses and affected the strain magnitude. The higher strain values in R copings group than GI copings group may be attributed to the better adhesive and mechanical properties of resin cement causing the marginal areas to withstand higher strain values before failure. Moreover, shrinkage of resin cement during setting may have caused stresses in the cervical margins of the copings with the effect being more obvious in thin margins [1].

Among the limitations of this study that dies and crown forms were fabricated with a flat occlusal morphology to achieve precision and reproducibility. The effect of fatigue and the presence of saliva may also be taken into consideration in future research.

CONCLUSION

1. Vertical knife edge finish line showed comparable fracture resistance with horizontal finishlines in ZrO_2 copings.

2. There is no evidence that the cementaion protocol either resin or glass ionomer affect the fracture resistance of ZrO_2 copings.

3. More conservative finish lines configurations copings measured the highest strain values before fracture.

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Conflict of interest

The authors have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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