Nanoleakage and internal adaptation of zirconia and lithium disilicate single crowns with feather edge preparation

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TO CITE THIS ARTICLE
Fuzzi M, Tricarico MG, Ferrari Cagidiaco E, Bonadeo G, Sorrentino R, Ferrari M. Nanoleakage and internal adaptation of zirconia and lithium disilicate single crowns with feather edge preparation. J Osseointegr 2017;9(2):250-62.

DOI 10.23806/JO.2017.09.02.03

ABSTRACT

Aim The present *in vitro* study aimed at investigating the nanoleakage and internal adaptation of zirconia and lithium disilicate single crowns with feather edge preparation.
Material and Methods Sound mandibular incisors were prepared and randomly divided first into 2 groups, accordingly to restorative materials, and then into 4 subgroups each, in relation to different luting agents. The samples were processed for nanoleakage and then observed for internal adaptation either with a stereomicroscope and a scanning electron microscope.
Results The average internal adaptation values were 54.06 µm and 78.66 µm for zirconia and lithium disilicate crowns respectively. The lithium disilicate restorations showed marginal fractures in 39% of the specimens whilst no fractures were observed in the zirconia group.
Conclusion Within the limitations of the present *in vitro* investigation, the feather edge preparation at the cervical margin can be recommended only when zirconia crowns are used.

KEYWORDS Internal adaptation; Nanoleakage; Zirconia crowns.

INTRODUCTION

In the last decade, porcelain-fused-to metal (PFM) restorations have been widely substituted by all-ceramic ones in dental practice. These new metal-free materials are used to achieve the optimum patients' esthetic expectations thanks to their natural-appearing characteristics, such as translucency, color stability and outstanding light transmission (1,2).
Since 1965, when McLean added Al_2O_3 to feldspathic porcelain to improve the mechanical properties (3), the research has led to the development of innovative all-ceramic materials, whose mechanical characteristics have been dramatically improved in order to provide suitable longevity and reduce technical problems (4). Nowadays, two all-ceramic dental materials could be used in most restorative situations for their optimal mechanical and esthetic characteristics: lithium disilicate glass ceramics and polycrystalline zirconium dioxide ceramics (2,5).
Zirconia has excellent mechanical properties (i.e. flexural strength: 900-1200 MPa), biocompatibility and adequate optical characteristics, expanding the possible applications of metal-free ceramic restorations also in the posterior regions, where higher fracture resistance is required (6).
To date, the best translucency and esthetic qualities are still provided by the group of glass ceramics; nonetheless, although new generation lithium disilicate-based materials just like IPS e.max (Ivoclar Vivadent, Schaan, Liecthenstein) have improved the mechanical properties (i.e. flexural strength: 300-400 MPa), they are recommended only for single-unit restorations and short-span fixed dental prostheses (FDPs) in anterior regions (2,7).
To achieve long-term success with all-ceramic restorations, correct marginal preparation, proper luting procedures and good marginal fit are mandatory.
Different cements have been investigated with all-ceramic materials and those containing organophosphate ester monomers have obtained the best results in terms of adhesive strength. Recent studies have shown that the combination of sandblasting and application of 10-methacryloyloxyidecyl-dihyidrogenphosphate monomer (MDP) provide the best results to cement zirconia crowns with resin composite luting agents (8). As to lithium disilicate ceramics, surface etching and silane application have been suggested to enhance strength and longevity of restorations (2).
Efficient clinical function is also significantly influenced by marginal and internal fit (9). Inaccurate marginal fit is responsible for plaque retention, increased risk of secondary caries, periodontal disease and endodontic inflammation affecting the health of underlying abutments. The exposure to oral fluids can lead to

FIG. 1 Sound mandibular central incisor.

FIG. 2 The rugby bur was first used to reduce the incisal and lingual surfaces.

3 A 3 B 3 C

3 D

FIG. 3 The tapered milling bur was used for axial and marginal reductions (3a: cervical reduction; 3b: axial reduction; 3c: intrasulcular reduction; 3d: lingual reduction).

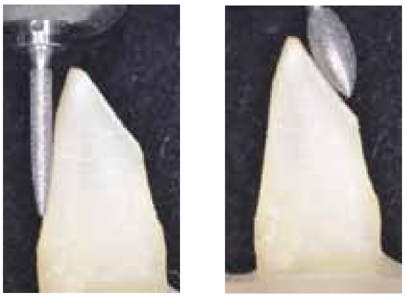


FIG. 4 Finishing of the preparation (4a: axial finishing; 4b: lingual finishing).

FIG. 5 Different views of the central incisor after preparation (5a: lateral view; 5b: front view).

cement breakdown and nanoleakage, decreasing restoration stability and durability. While it is not clear if a clinically acceptable range of marginal discrepancy can be advised to be less than 120 µm (10), in Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) and copy-milling systems the marginal opening has been reported to range between 60 µm and 300µm(10-15).
Marginal fit is also influenced by the finish line, from the traditional chamfer and shoulder geometries to the feather edge preparation (16).
The feather edge finish line was historically conceived for metal or PFM restorations (17). The efficiency of this type of marginal preparation has been validated experimentally (18) and clinically (19).
A recent paper by Reich et al. (20) showed the promising results of the feather edge preparation for zirconia copings compared with the more common chamfer finish line. However, the type of restorative material and the thickness of the crown margins can be related to the stiffness of the material itself and the needs of the patients (21-22).
In the present study the sealing capability, cement thickness and marginal integrity of the feather edge marginal preparation were evaluated on mandibular incisors comparing two different all-ceramic materials (i.e. lithium disilicate and zirconia) and four luting agents.
The tested null-hypotheses stated that: 1) there was no association between different ceramic dental materials and different luting systems in terms of interfacial nanoleakage, internal fit and marginal integrity; 2) there was no association between finish line preparation and marginal fracture in any tested ceramic-cement combination.

MATERIALS AND METHODS

Tooth preparation

Sixty-four human mandibular incisors, extracted for periodontal reasons, were used in this study. The teeth were stored in 0.5% chloramine-T solution at 4°C immediately after extraction to prevent bacterial growth. An expert prosthodontist performed standardized tooth preparations to receive single crowns (Fig. 1-5). The incisal and lingual surfaces were reduced by approximately 1.0 mm using first a green ring rugby milling bur (Komet Dental, ISO8368314023, LOT 189567, Lemgo, Germany) and then a red ring rugby milling bur (Komet Dental, ISO 806314012, LOT 624719). The axial walls were prepared with a convergence angle of 10° and feather edge cervical preparation margins were placed in cementum-dentin following the cementum-enamel junction (CEJ) using first a coarse grit tapered milling bur (Komet Dental, ISO 862314016, LOT 241757) and then a red ring tapered milling bur (Komet Dental, ISO 806314012, LOT 53167) under constant water cooling (Fig. 1-5). The impressions of each prepared tooth were taken using polyether impression materials (Impregum, 3M ESPE, Seefeld, Germany). Then, the master casts were poured with type IV extra-hard stone (Fuji Rock,

GC, Leuven, Belgium) following the manufacturer's recommendations.
The specimens were randomly divided into 2 groups (n = 32) according to the type of restorative material (i.e. zirconia vs lithium disilicate); then each group was in turn randomly divided into 4 subgroups (n = 8) according to the luting agent as follows.

Group 1) Pressed IPS e.max lithium disilicate (Ivoclar Vivadent)

a. dual curing resin cement (Variolink II, Ivoclar Vivadent).
b. self-adhesive resin cement (G- CEM Automix, GC).
c. self-adhesive resin cement(G- CEM LinkAce, GC).
d. resin-modified glass-ionomer cement (Ketac-Cem Plus Automix, 3M ESPE).

Group 2) AAdva Zirconia (GC)

a. dual curing resin cement (Variolink II, Ivoclar Vivadent).
b. self-adhesive resin cement (G- CEM Automix, GC).
c. self-adhesive resin cement (G- CEM LinkAce, GC).
d. resin-modified glass-ionomer cement (Ketac-Cem Plus Automix, 3M ESPE).

All the restorations were fabricated with a CAD/CAM system (Exocad DentalCAD, Exocad GmbH, Darmstadt, Germany). For both zirconia and lithium disilicate crowns, the amount of internal relief and resulting tightness was controlled with the cement space thickness setting of the CAD software; the virtual spacer was set at 30 µm.
After milling, the fit of the crowns was carefully evaluated in the dental laboratory by means of a stereomicroscope at 40x magnification and no evident gaps were noticed.

Cementation procedures

In each experimental group, the cementation procedures recommended by the manufacturers were strictly followed. All the specimens were stored in a laboratory oven at 37°C and 100% relative humidity for 24 h and then prepared for the interfacial nanoleakage analysis.
All the abutments were cleaned with prophylaxis brushes and pumice powder before luting the corresponding crowns.
The internal surfaces of the zirconia crowns were sandblasted with 50 µm alumina powder at 1 atm while those of the lithium disilicate restorations were etched with 5% hydrofluoric acid for 20 s and then silanized with Monobond (Ivoclar Vivadent).

Subgroups a: Excite DSC and Variolink II (cement 1)

Phosphoric acid gel at 37% was applied onto the prepared dentin. The etchant was left to react for 15 s on the dentin and then thoroughly removed with a vigorous water spray for at least 5 s. Excess moisture was removed leaving the dentin surface with a glossy wet appearance. Excite DSC (Ivoclar Vivadent) was applied onto the dentin with a scrubbing action for 10 s. Variolink II was then applied to the inner surface of the restoration. The crown was placed in situ with slight finger pressure and the excesses were removed with a microbrush. The luting procedures were performed under a constant pressure of 1 kg (0.098 MPa). The restoration was left to set under constant pressure for 20 s and then light-curing was performed for 40 s on each surface.

Subgroups b: G-CEM Automix (cement 2)

The two GC Primer A/B were mixed in a 1:1 ratio and then applied to all preparation surfaces using a microbrush with a scrubbing action for 15 s. A reaction time of 15 s is recommended onto the dentin. GC Primer excess was dispersed with a strong stream of air until the mobile liquid film was no longer visible. No light-curing was applied. G-CEM Automix was then applied to the inner surface of the restoration. The excess material was removed immediately with a microbrush.
Luting procedures were performed under a constant pressure of 1 kg (0.098 MPa) until polymerization of the cement was complete. The material was left to self-cure for the first 5 min and then additional light polymerization was performed for 40 s on each surface.

Subgroups c: G-Cem LinkAce (cement 3)

The internal surface of the restoration was coated with G-Cem LinkAce and seated immediately under constant pressure. The surfaces were light-cured for 4 s each and then the excesses were removed using a microbrush.
Maintaining a constant pressure of 1 kg (0.098 MPa), the material was light-cured on the palatal and buccal sides for 40 s. The material was then left to set for 4 more min.

Subgroups d: Ketac-Cem Plus Automix (cement 4)

As to glass-ionomer cementation, the prepared dentin was dried using cotton pellets, the Ketac-Cem Plus Automix was then applied to the inner surface of the restoration. The excess material was removed immediately with a microbrush. Luting procedures were performed under a constant pressure of 1 kg (0.098 MPa) until polymerization of the cement was complete.

Nanoleakage and fracture analyses

The specimens for interfacial nanoleakage analysis were prepared according to procedures described in previous studies (20). The teeth were covered with nail varnish up to 1 mm from the margins of each crown; then the specimens were kept in a 50 wt% ammoniacal $AgNO3$ solution for 24 hours and finally in a photo-developing solution.
The specimens were totally embedded in epoxy resin (Epoxy embedding medium kit, #45359, Sigma Aldrich, St. Louis, MO, USA) and cut longitudinally (i.e. oral-

buccaly) to a thickness of 1 mm. From each specimen, 5-6 sections were made. A custom designed diamond blade was used to cut zirconia at low speed under water cooling (Low speed Isomet Saw 1000, Buehler, Milano, Italy).

Two central slabs were randomly chosen from each specimen for a total of 16 slabs per group. The sections (n = 128) were then ground down to a thickness of 40µm using wet carbide papers mounted on a specially designed grinding machine (Micromet, Remet, Bologna, Italy). The slices were stained with acid fuchsin and observed with a transmitted light microscope (Nikon Eclipse, Nikon, Tokyo, Japan). Images of all interfaces were obtained at 100× magnification and the amount of silver deposits along the interface between the luting agent and dentin was quantified by two 2 independent calibrated observers in double blind in accordance with the following scores.

- 0 = no nanoleakage.
- 1 = 0-10% of adhesive interface showing nanoleakage.
- 2 = 11-20% of adhesive interface showing nanoleakage.
- 3 = 21-30 % of adhesive interface showing nanoleakage.
- 4 = 31-40% of adhesive interface showing nanoleakage.
- 5 = 41-50% of adhesive interface showing nanoleakage.
- 6 = 51-60% of adhesive interface showing nanoleakage.
- 7 = 61-70% of adhesive interface showing nanoleakage.
- 8 = 71-80% of adhesive interface showing nanoleakage.
- 9 = 81-90% of adhesive interface showing nanoleakage.
- 10 = 91-100% of adhesive interface showing nanoleakage.

Light microscope and SEM analyses

After nanoleakage evaluation, all the 16 sections per group were processed with 2 different microscopes: transmitted light microscope (Nikon Eclipse Ni H550L, Nikon) and scanning electron microscope (SEM) (JSM 6060, J EOL, Tokyo, Japan)(Fig. 6-16). On each section, the cement thickness was measured in microns at the cervical margins. The two cervical margins were considered a unique absolute measurement; the recorded value was the average of all the cervical margins.

The presence of fracture lines and their levels along the crown margins were evaluated as well and recorded in each group.

Statistical analysis

Nanoleakage scores were compared among the groups using the Kruskall–Wallis Analysis of Variance (ANOVA) followed by the Dunn's Multiple Range test for post hoc comparisons.

A Two-Way ANOVA and two separate One-Way ANOVA's were run in order to compare cement thickness at different levels within the same group and between different groups at the same level. The One-Way ANOVA was followed by the Tukey's post hoc test for multiple comparisons as needed.

In all the analyses the level of significance was set at $p < 0.05$.

RESULTS

Nanoleakage

The nanoleakage analysis showed that the staining solution always diffused between the dentin surface and the luting agent (Fig. 6-13, 15-16). The degree of penetration of the dye varied in relation with the type

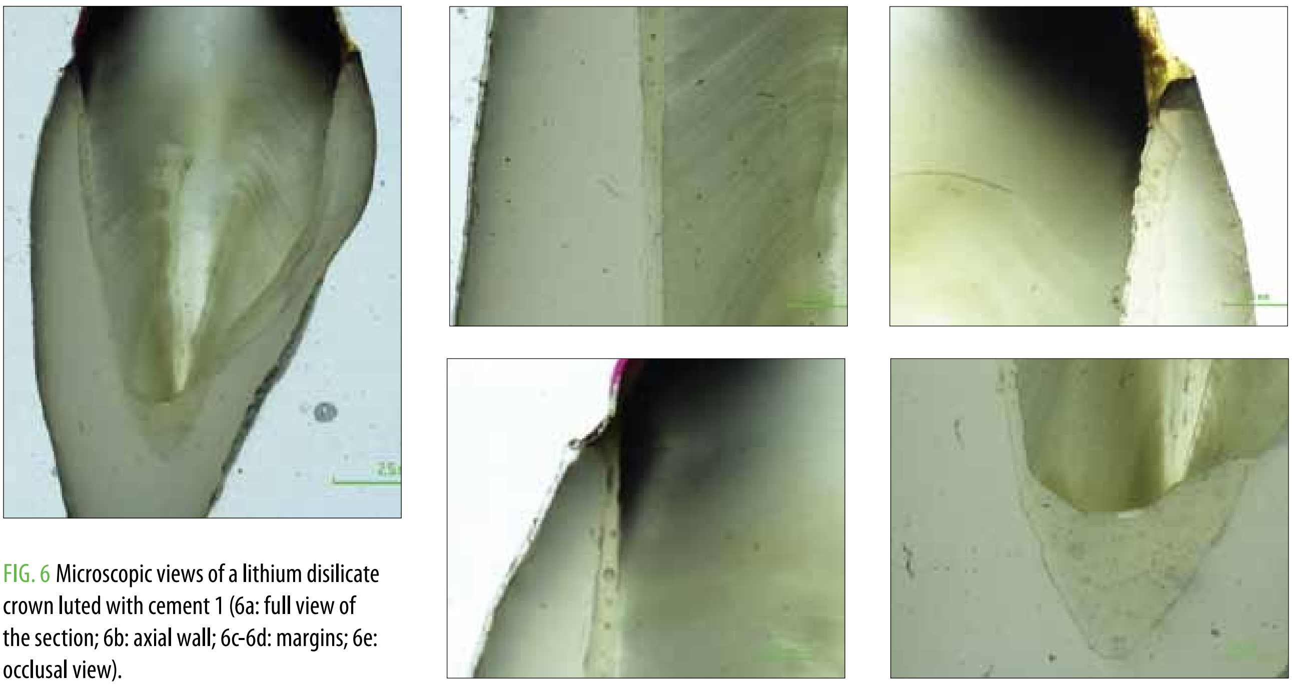


FIG. 6 Microscopic views of a lithium disilicate crown luted with cement 1 (6a: full view of the section; 6b: axial wall; 6c-6d: margins; 6e: occlusal view).

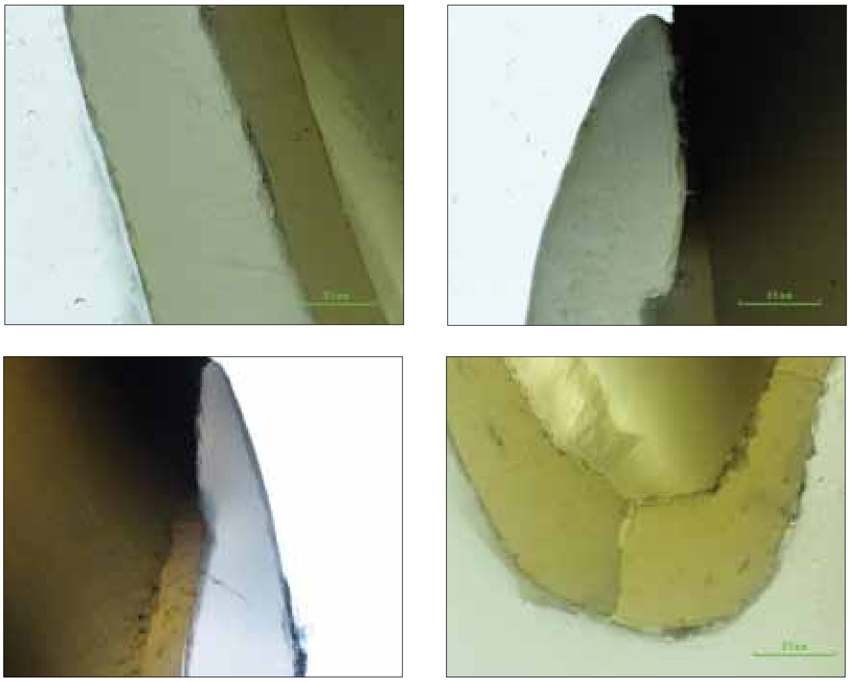



FIG. 7 Microscopic views of a lithium disilicate crown luted with cement 2 (7a: full view of the section; 7b: axial wall; 7c-7d: margins; 7e: occlusal view).

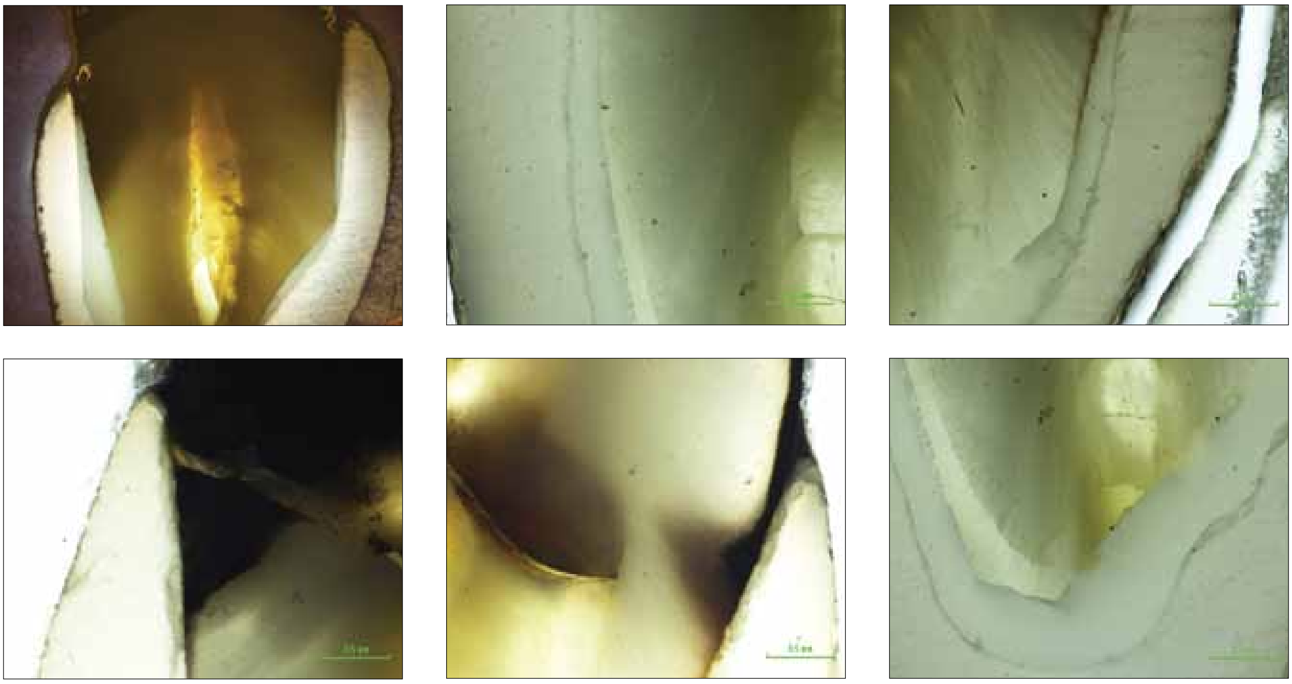


FIG. 8 Microscopic views of a lithium disilicate crown luted with cement 3 (8a: full view of the section; 8b-8c: axial walls; 8d-8e: margins; 8f: occlusal view).

of luting-bonding combination. No group showed perfect seal.
The cement used in subgroups a in combination with both lithium disilicate and zirconia crowns showed the lowest nanoleakage scores whilst the cement used in subgroups b showed the highest scores (Table 1-3).
Descriptive statistics of nanoleakage scores of lithium disilicate and zirconia groups are reported in Tables 1-4, along with significant differences according to the post hoc test. The Kruskal-Wallis ANOVA revealed the existence of significant differences among groups in nanoleakage scores ($p = 0.05$). Specifically, the Dunn's Multiple Range Test pointed out that, when lithium disilicate was evaluated, the cement of subgroups a yielded significantly lower nanoleakage than the cements of subgroups b and c, but not of the cement of subgroups d (Table 1); conversely, when zirconia crowns were tested, the only statistical difference was found between the

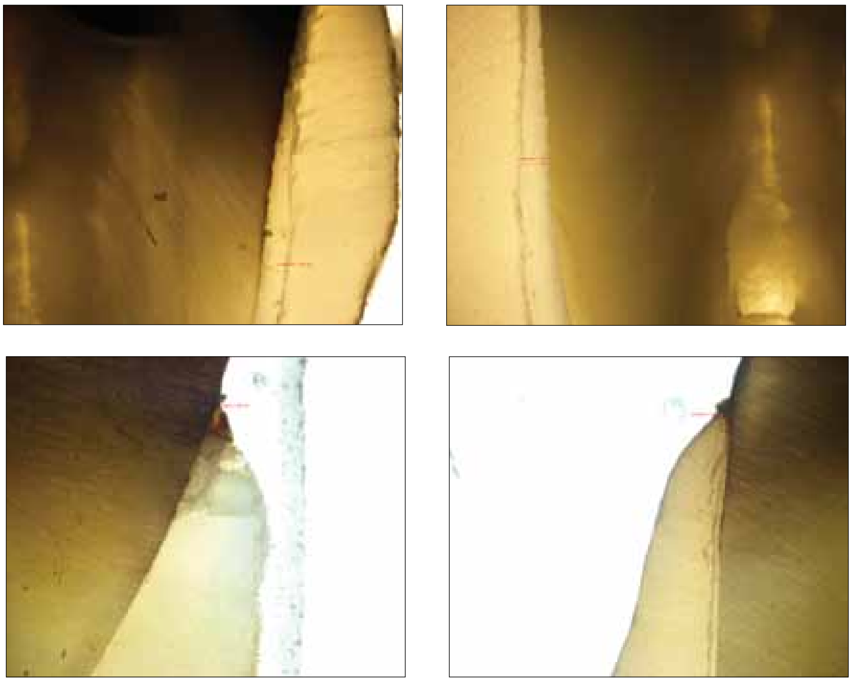


FIG. 9 Microscopic views of a lithium disilicate crown luted with cement 4 (9a: full view of the section; 9b-9c: axial walls; 9d: margins; 9e: occlusal view).

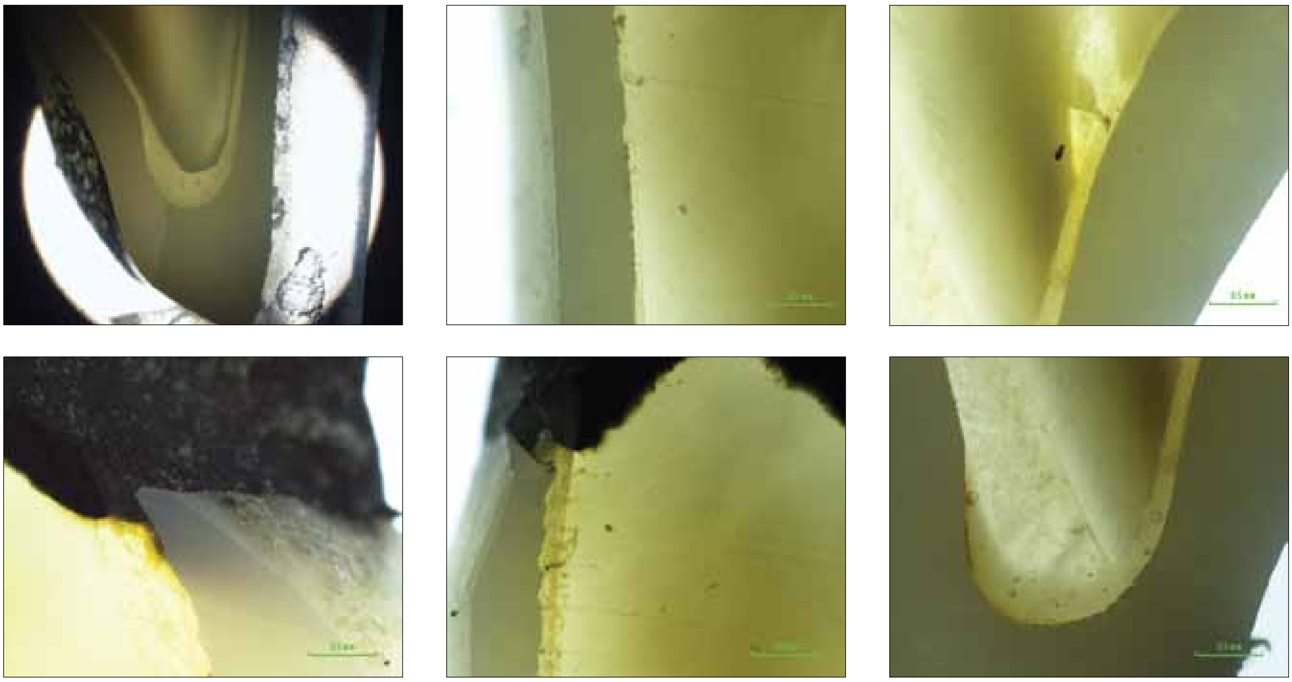


FIG. 10 Microscopic views of a zirconia crown luted with cement 1 (10a: full view of the section; 10b-10c: axial walls; 10d-10e: margins; 10f: occlusal view).

Group	N	Median	25%	75%	Significance p<0.05
Disilicate cement 1	16	1	1	2	A
Disilicate cement 2	16	3	2.5	4	B
Disilicate cement 3	16	2	2	3	B
Disilicate cement 4	16	2	2	2.5	AB

TABLE 1 Lithium disilicate nanoleakage Kruskal-Wallis ANOVA ($p<0.001$), followed by the Dunn's Multiple Range test for post hoc comparisons ($p<0.05$). In the significance column, different letters label significantly different groups.

Group	N	Median	25%	75%	Significance p<0.05
Zirconia cement 1	16	1	1	1	A
Zirconia cement 2	16	2	1	2	B
Zirconia cement 3	16	1	1	2	AB
Zirconia cement 4	16	2	1	2	AB

TABLE 2 Zirconia nanoleakage Kruskal-Wallis ANOVA ($p<0.018$), followed by the Dunn's Multiple Range test for post hoc comparisons ($p<0.05$). In the significance column, different letters label significantly different groups.

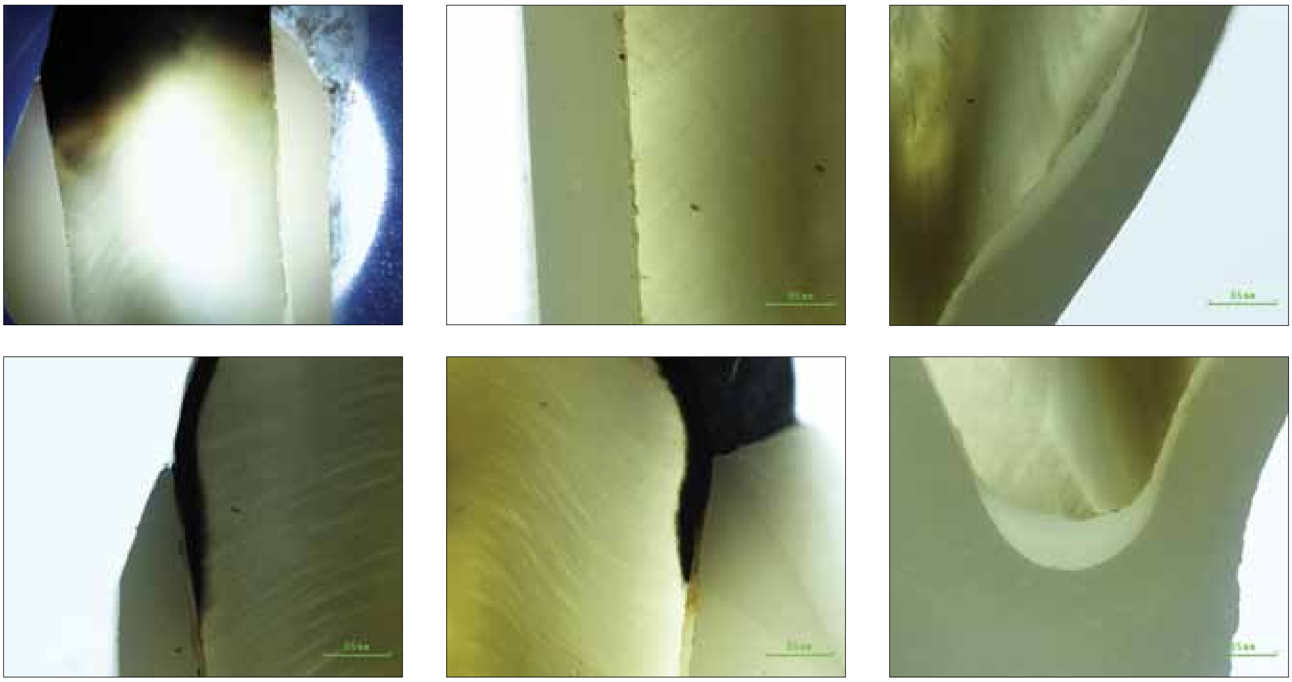


FIG. 11 Microscopic views of a zirconia crown luted with cement 2 (11a: full view of the section; 11b-11c: axial walls; 11d-11e: margins; 11f: occlusal view).

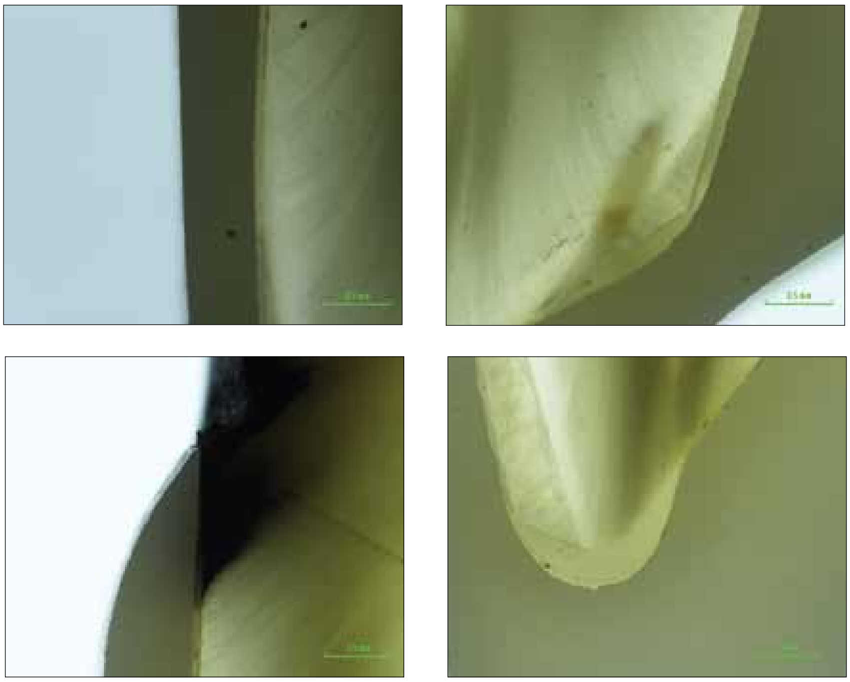


FIG. 12 Microscopic views of a zirconia crown luted with cement 3 (12a: full view of the section; 12b-12c: axial walls; 12d: margins; 12e: occlusal view).

luting agents of subgroups a and b (Table 2).

When all the cements and crowns were statistically evaluated together, the luting agent used in subgroups b in combination with lithium disilicate crowns showed the worst leakage scores, whilst the cement used in subgroups a in combination with zirconia crowns demonstrated the best scores (Table 3).

Marginal fractures

Regarding the presence of fractures within the crown materials, no fractures were observed in zirconia crowns (Fig. 15) whilst they were noted in 25 samples made of lithium disilicate (39%) (Fig. 15). All the fractures were observed at the cervical margins of the crowns, where the thickness of the lithium disilicate was thinner due to the feather edge finish line. The fractures were evident in both SEM (Fig. 14) and stereomicroscopic observations (Fig. 15). There were not statistically significant

Group	N	Median	25%	75%	Significance p<0.05
Disilicate cement 1	16	1	1	2	AB
Disilicate cement 2	16	3	2.5	4	D
Disilicate cement 3	16	2	2	3	CD
Disilicate cement 4	16	2	2	2.5	BCD
Zirconia cement 1	16	1	1	1	A
Zirconia cement 2	16	2	1	2	BCD
Zirconia cement 3	16	1	1	2	ABC
Zirconia cement 4	16	2	1	2	ABC

TABLE 3 Lithium disilicate vs zirconia nanoleakage Kruskal-Wallis ANOVA ($p<0.001$), followed by the Dunn's Multiple Range test for post hoc comparisons ($p<0.05$). In the significance column, different letters label significantly different groups.

Group	N	Fractures	Significance p<0.05
Disilicate cement 1	16	5	A
Disilicate cement 2	16	7	A
Disilicate cement 3	16	6	A
Disilicate cement 4	16	7	A
Zirconia cement 1	16	0	B
Zirconia cement 2	16	0	B
Zirconia cement 3	16	0	B
Zirconia cement 4	16	0	B

TABLE 4 Lithium disilicate vs zirconia fractures Kruskal-Wallis ANOVA ($p<0.001$), followed by the Dunn's Multiple Range test for post hoc comparisons ($p<0.05$). In the significance column, different letters label significantly different groups.

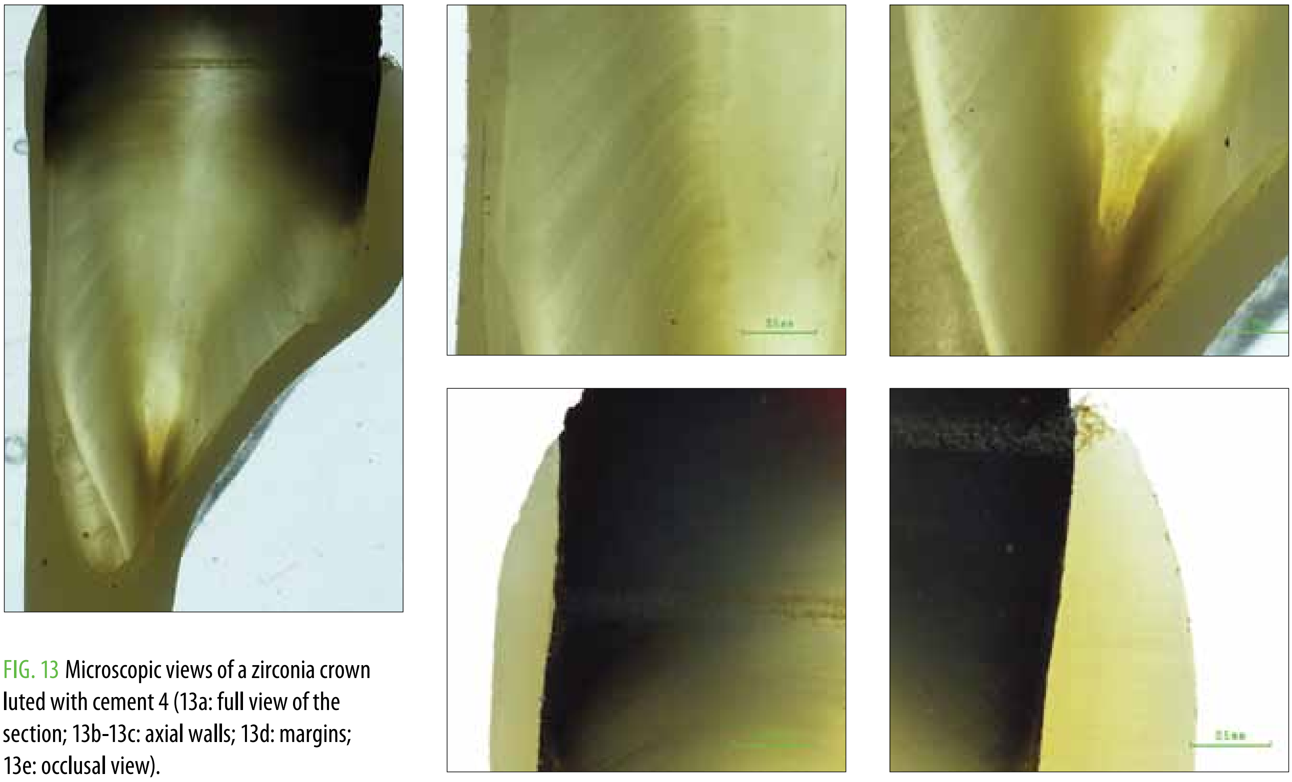
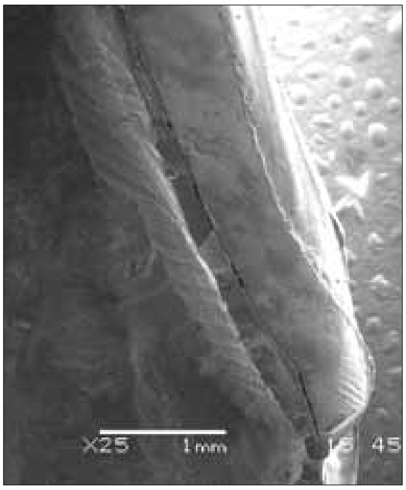


FIG. 13 Microscopic views of a zirconia crown luted with cement 4 (13a: full view of the section; 13b-13c: axial walls; 13d: margins; 13e: occlusal view).

Group	N	Axial walls	Standard Deviation	Occlusal area	Standard Deviation
Disilicate cement 1	16	74.33 A	68.05	245.59 B	150.69
Disilicate cement 2	16	79.53 A	75.18	235.66 B	189.60
Disilicate cement 3	16	70.12 A	62.82	205.35 B	175.12
Disilicate cement 4	16	80.73 A	72.58	195.41 B	183.25
Zirconia cement 1	16	62.34 A	48.51	214.07 B	176.78
Zirconia cement 2	16	55.57 A	44.40	225.28 B	190.93
Zirconia cement 3	16	68.49 A	63.80	190.18 B	145.91
Zirconia cement 4	16	64.43 A	69.65	235.39 B	170.25

TABLE 5 Cement thickness in µm at axial walls and occlusal area. Different letters label significantly different groups ($p<0.05$).



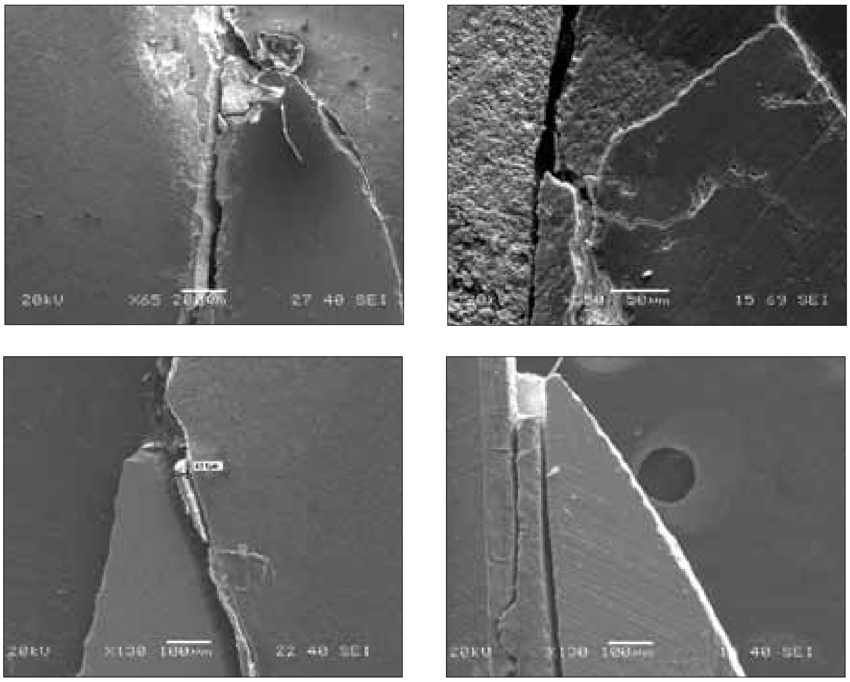


FIG. 14 SEM images (14a: sample crown before cutting at 25x; 14b-14c: two margins of lithium disilicate crowns showing fractures at 65x and 350x; 14d-14e: two intact margins of zirconia crowns at 130x).

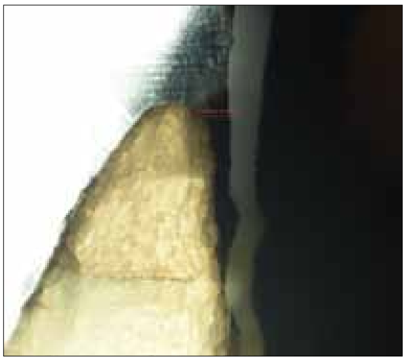


FIG. 15 Microscopic images showing fractured margins of lithium disilicate crowns (4x, 10x).

differences among the four cements inside each group of crowns but there were significant differences between zirconia and lithium disilicate crowns (Table 4).

Marginal gap

Descriptive statistics of cement layer thicknesses were reported in Tables 5-8. When cement layer thicknesses were compared within each crown-cement system, the cement layer was significantly thicker at the occlusal wall. Similar cement thicknesses regardless of the crown-cement system were also measured at the axial walls and cervical margins as well. At the axial walls, no significant

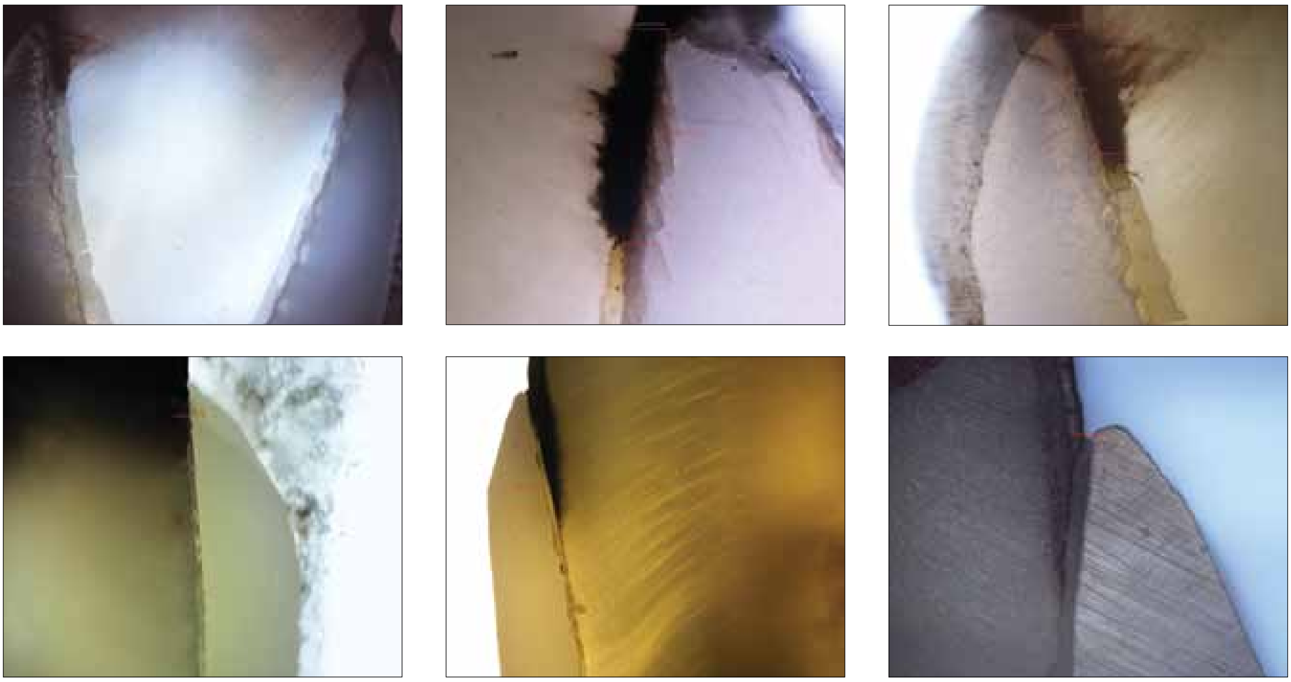


FIG. 16 Microscopic images showing nanoleakage of a lithium disilicate (16a-16c) and of a zirconia crown (16d-16f).

differences emerged among the tested crown-cement systems; conversely, at the cervical margins, significant differences were found (Fig. 16).
The mean value of cement thickness at cervical margins of the lithium disilicate crowns groups was 78.66 µ whilst a mean value of 54.06 µ was reported in the zirconia crowns groups.
When all the cements and crowns were statistically evaluated together, the cement 1 in combination with lithium disilicate crowns showed the widest marginal gaps whilst the cement 2 in combination with zirconia crowns showed the smallest ones (Table 8).
As the data distribution was not normal, the Kruskall-Wallis ANOVA was used to assess the statistical significance of between-group differences, followed by the Dunn's Multiple Range test for post hoc comparisons. The Kruskall-Wallis ANOVA showed that zirconia groups differed significantly ($p=0.04$). In the Significance column of the table, different letters label significantly different groups.

Disilicate subgroup	N	Mean	Standard Deviation	Median	Interquartile range
1	32	103.75	110.59	70	40-135
2	32	84.68	85.23	50	40-110
3	32	64.37	25.01	60	40-110
4	32	61.87	37.10	50	40-110

TABLE 6 Cement thickness in µm at cervical margins of lithium disilicate crowns. As the data distribution was not normal, the Kruskal-Wallis ANOVA was used to assess the statistical significance of between-group differences. No statistically significant differences emerged among the lithium disilicate restorations ($p=0.43$).

DISCUSSION

In the present study, mandibular incisors were selected since their size and shape require less invasive preparations, minimizing tooth weakening and reducing the clinical risk of pulp irritation.
According to the results of the present *in vitro* study, the 1) null-hypothesis was rejected, since statistically significant differences between the two different all-ceramic materials and the different luting system were noticed as to interfacial nanoleakage scores.
The nanoleakage analysis was used to test the differences in the sealing capability between the tested groups. This procedure has already been used to evaluate the nanoleakage infiltration of other restorative materials and techniques, such as adhesives and resin composites (24–27) but few studies tested the silver infiltration after cementation of all-ceramic crowns (28, 29).
The combination of crown and cement suggested by the manufacturers was the starting point of this study. Nanoleakage was detected in all the groups between dentin and adhesive/cement layers. The nanoleakage scores showed statistically significant differences: in particular, the cement 2 in combination with lithium disilicate crowns showed the worst leakage scores whilst the cement 1 in combination with zirconia crowns demonstrated the best behavior. This can be explained

Zirconia subgroup	N	Mean	Standard Deviation	Median	Interquartile range	Significance $p<0.05$
1	32	70.94	65.17	55	30-90	A
2	32	36.56	15.78	30	20-45	B
3	32	57.50	45.08	40	25-85	AB
4	32	51.25	24.98	50	30-65	AB

TABLE 7 Cement thickness in μm at cervical margins of zirconia crowns. As the data distribution was not normal, the Kruskal-Wallis ANOVA was used to assess the statistical significance of between-group differences, followed by the Dunn's Multiple Range test for post hoc comparisons. The Kruskal-Wallis ANOVA showed that zirconia groups differed significantly ($p=0.04$). Different letters label significantly different groups ($p<0.05$).

Disilicate subgroup	N	Mean 78.66	Standard Deviation	Median	Interquartile range	Significance $p<0.05$
1	32	103.75	110.59	70	40-135	C
2	32	84.68	85.23	50	40-110	BC
3	32	64.37	25.01	60	40-110	B
4	32	61.87	37.10	50	40-110	B
Zirconia subgroup	N	Mean 54.06	Standard Deviation	Median	Interquartile range	Significance $p<0.05$
1	32	70.94	65.17	55	30-90	B
2	32	36.56	15.78	30	20-45	A
3	32	57.50	45.08	40	25-85	AB
4	32	51.25	24.98	50	30-65	AB

TABLE 8 Cement thickness in μm at cervical margins of lithium disilicate and zirconia crowns. As the data distribution was not normal, the Kruskal-Wallis ANOVA was used to assess the statistical significance of between-group differences, followed by the Dunn's Multiple Range test for post hoc comparisons. The Kruskal-Wallis ANOVA showed that zirconia groups differed significantly ($p=0.04$). Different letters label significantly different groups ($p<0.05$).

by the fact that in the subgroups a a total-etch bonding procedure seals the dentin better than in the other groups, where a self-etching procedure was used. This is in accordance with the findings of Bernal et al. (30). However, from the results of the present study, it was also evident that no perfect seal was found in all the tested groups.

The nanoleakage scores observed in the four groups of lithium disilicate samples showed worse seal than the corresponding zirconia groups; this can be due to the presence of fractures at the cervical margins of lithium disilicate crowns. Consequently, the type of preparation could be responsible for different nanoleakge scores of lithium disilicate crown groups; lithium disilicate could be too brittle to hold thin thicknesses at the margins when feather edge preparation was performed.

The internal surfaces of the zirconia and lithium disilicate crowns were treated with sandblasting and hydrofluoric etching in combination with silanization respectively. In both groups, the samples showed good cement adaptation to the conditioned surfaces and no nanoleakage was found between the restorations and the luting material.

The 2) null hypothesis was rejected, since fracture lines were noticed at the cervical margins of some crowns. Particulraly, fractures were observed in the lithium disilicate groups whilst no fractures were detected in the zirconia groups. Consequently, it can be stated that zirconia crowns can be prepared with feather edge cervical margins, since zirconia is stiff enough to withstand marginal fractures.

The choice to perform feather edge marginal preparations was done to test if zirconia and lithium disilicate ceramics can be effective to produce esthetic crowns and, in the mean time, hold stress in very thin thickness. The crown margins showed some imprecisions that may be related to the ditching of the abutments: due to the presence of a vertical preparation area at the cervical margin, it may be difficult to be precisely detected. However, because of the geometry of the feather edge margins and the total occlusal convergence of the axial walls at 10°, the amount of exposed cement was very limited and, consequently, the possible dissolution of the cement or the plaque accumulation on it could be very limited.

The cement thickness was evaluated with both stereomicroscopy and scanning electron microscopy at three different levels: at occlusal, axial and cervical areas. The thickness of the cement at occlusal level was the greatest; this was due to the fact that the space between the occlusal wall of the preparation and the internal surface of the crown works as a chamber to

allow a good marginal adaptation of the crown itself.
The marginal fit can be defined as the distance between the preparation and the crown margin; it relates to the cement thickness as during cementation procedures this space will be filled with cement. The accuracy of a restoration is the best when the least amount of cement is left at the cervical marginal and axial walls.
The discrepancy observed at cervical margins varied considerably based on external or internal evaluations (31). It is not clear if the gap can be accepted, although an amount within 124 µ is to date considered clinically acceptable (10, 11). It must be pointed out that several studies have compared external and internal marginal adaptation and in most cases the initial results showed a lower gap than those obtained after cutting the samples to observe the internal margins (31, 32).
In this study, the internal marginal fit and consequently the cement thickness at the margin was evaluated. It was clearly noted that all groups were in a range of clinical acceptability, if a discrepancy of 100 µ is considered valid (32–34).
It is commonly believed that a better adaptation of a restoration leads to lower infiltration, as it may lead to an increase in the cement dissolution with a potential for leakage (5, 34). However, the results of the present study showed that the group with the lowest score of nanoleakage had the worst marginal fit (i.e. cement 1). This allows to speculate that there is no direct correlation between marginal fit and nanoleakage infiltration. Consequently, the results obtained with the nanoleakage analysis and SEM observations pointed out that the marginal fit can be considered less important than the used cement-bonding combination. In fact, leakage at the margins can lead to postoperative sensitivity, leakage and secondary pulp pathology whilst the cement thickness by itself does not contribute to a premature failure of a restoration.
These results were partially expected and in agreement with existing literature but for the glass-ionomer based cement; the good results obtained with this cement can be due to the fact that the luting agent is reinforced with resin, resulting in a flowability sufficient to penetrate and seal the sandblasted zirconia surface and the etched and silanized lithium disilicate surface as well.
Relevant differences between the two all-ceramic materials used to fabricate the tested crowns must be pointed out: zirconia has shown better results in terms of nanoleakage, lower cement thickness and the crown margins were generally not damaged.
The microscopic analysis of the integrity of the margins was performed with both SEM and stereomicroscope. The double observation of each selected section was performed first with the stereomicroscope and then with SEM, in order not to create any artifact due to vacuum procedure. In all the sections, the zirconia margins were free from any fracture and/or chipping whilst horizontal line fractures and/or chippings were detected at the feather edge margins of the lithium disilicate crowns. Chipping and fracture lines of the margins may be due to the cutting procedures but they can also be due to the relatively low stiffness of the material itself when compared to zirconia.
Several recent papers reported the short term performances of zirconia and lithium disilicate crowns under clinical conditions (35-38). All these retrospective studies showed positive results for both materials. Whilst it can be expected that zirconia crowns with feather edge margins can keep their integrity for many years, it is questionable, accordingly with the results of this *in vitro* study and others related to flexural strength tests (39-40), if lithium disilicate crowns can have a long term preservation of margins and consequently a good clinical prognosis. Since the fractures of lithium disilicate margins were noticed when the margins themselves became thinner than 0.5-1.0 mm, it is possible that such microfractures might be not easily detectable clinically. Longer clinical trial results obtained from prospective studies are desirable in order to clarify the clinical behavior of lithium disilicate crowns with feather edge marginal preparation.
The present *in vitro* study was a preliminary evaluation of the marginal adaptation of two different types of all-ceramic crowns with feather edge margins. A protocol with thermal cycles and cyclic loading would be desirable to confirm the results of the present investigation. Randomized clinical trials to evaluate the four crown-bonding-luting combinations tested in this study are underway in order to evaluate medium-long term results.

CONCLUSIONS

Within the limitations of the present *in vitro* investigation, the following conclusions were drawn

- the feather edge preparation can be advocated for teeth that do not have abundant dentin and residual coronal structure, so as to reduce the risk of pulp inflammation;
- the feather edge preparation at the cervical margin is strictly recommended only when zirconia crowns are used.

Acknowledgements

The authors would like to thank GC Co. and Ivoclar Vivadent that generously provided the materials necessary to perform the present investigation, Prof. Cecilia Goracci for the statistical analyses and DT Mr. Stefano Petreni who fabricated part of the prosthetic crowns.

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