In vitro analysis of the fracture resistance of CAD-CAM monolithic lithium disilicate molar crowns with different occlusal thickness

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ABSTRACT

Aim To compare the fracture resistance and mode of failure of CAD-CAM monolithic lithium disilicate crowns with different occlusal thickness.

Materials and methods Thirty CAD-CAM monolithic lithium disilicate crowns with different occlusal thickness were randomly distributed into 3 experimental groups: 0.5 mm (group 1), 1.0 mm (group 2) and 1.5 mm (group 3). The restorations were cemented onto human molars with a self-adhesive resin cement. The specimens were loaded until fracture; the fracture resistance and mode of failure were recorded. The data were statistically analyzed with the one-way ANOVA followed by the Fisher's Exact test with Bonferroni's correction ($p=0.05$).

Results The fracture resistance values of all the specimens exceeded the maximum physiological occlusal loads in molar regions. The highest fracture resistance was noticed in 1.0 mm-thick crowns. Ultrathin restorations (group 1) proved to be statistically less resistant to fracture than those of the other experimental groups ($p<0.05$). The crowns were mainly interested by unrestorable fractures.

Conclusions The occlusal thickness of CAD-CAM monolithic lithium disilicate crowns influences either the fracture resistance and the mode of failure of the restorations; the occlusal thickness of such restorations can be reduced up to a lower bound of 1.0 mm in order to keep sufficient strength to withstand occlusal loads; CAD-CAM monolithic lithium disilicate crowns showed sufficient fracture resistance to be used in molar regions but not in an ultrathin configuration (0.5 mm).

KEYWORDS CAD-CAM, Fracture resistance, Lithium disilicate ceramic, Monolithic crown, Occlusal thickness.

INTRODUCTION

In the last decade, the development of innovative fabrication technologies and the implementation of restorative material science has led to a massive introduction of all-ceramic restorations in clinical dental practice (1-3). Particularly, monolithic crowns have allowed for both mechanical and biological improvements, due respectively to the avoidance of veneering porcelain chipping, no more present as in bilayered restorations, and to the preservation of tooth tissues, as room for opaque and esthetic ceramic is no longer required; moreover, all-ceramic restorations guarantee a more natural tooth-like appearance, achieving astounding esthetics and optimal translucency (4,5).

In this scenario, lithium disilicate glass ceramics have gained popularity among dentists because of undeniable advantages, such as reliable mechanical properties, high esthetic potential and wear behavior very similar to opposing dental enamel (2,4).

Lithium disilicate ceramics can be used with both

conventional heat pressing procedures and Computer Aided Design-Computer Aided Manufacturing (CAD-CAM) fabrication techniques; the latter allow for standardized processing of the material, reduce production times and improve cost effectiveness (4,6).
According to the principles of minimal intervention dentistry, the preservation of sound tooth tissues is nowadays paramount in clinical practice; this trend caused a significant shift in prosthodontic strategies, limiting prosthetic preparations to the removal of damaged tissues and using the benefits offered by adhesive cementation techniques to incorporate very thin ceramic restorations even in the presence of not retentive preparation geometries (2,7-9). Differently from zirconia, whose polycrystalline content does not allow for conventional etching procedures, lithium disilicate ceramics are basically glass materials and their surface characteristics can be positively modified with conventional acid etching techniques (10,11).
In order to keep as much dental tissues as possible, the reduction of the occlusal thickness of prosthetic restorations is crucial particularly in posterior regions, where the use of high strength, monolithic, all-ceramic materials can be fundamental to preserve tooth vitality (2,7,12); moreover, the use of etchable, adhesive restorative materials can enhance the mechanical performances of restorations, due to better functional stress distribution at the adhesive interface (13).
Although the mechanical properties of lithium disilicate ceramics exceed those of many restorative materials, the manufacturers' guidelines suggest a minimum restoration thickness of 1.0 mm to avoid fractures (4,14). Nonetheless, a minimum recommended thickness for monolithic lithium disilicate single crowns validated by scientific data has not been established yet and there is no consensus on how thin restorations can be made (14,15). To date, few laboratory data about the mechanical predictability of monolithic lithium disilicate crowns are available in the literature, particularly for the so called "ultrathin" configuration (i.e. up to a thickness of 0.5 mm), as well as the validation of their clinical performances in the oral environment (2,4).
Previous *in vitro* investigations showed that monolithic lithium disilicate crowns exhibited fracture loads higher than those reported for layered restorations (16,17). Furthermore, 0.5 mm wall thickness was not enough to withstand functional loads in posterior regions safely, whereas 1.0 and 1.5 mm thick crowns showed appropriate fracture resistance (2,14,15).
Although laboratory investigations showed that monolithic lithium disilicate crowns luted with resin cements showed higher failure loads compared with glass ionomer cements, the type of luting agent does not seem to negatively influence either the *in vitro* strength and the clinical survival rates in the short and medium term (18,19).
As to clinical studies, recent multicentric retrospective studies on posterior lithium disilicate SCs up to 6 and 12 years reported overall survival rates of 95.46% and 97.93% respectively, highlighting bulk fractures of the material in the failed teeth (7,9). Similar results were noticed in retrospective investigations with 81.9% and 96.1% of survival after 15 and 9 years of clinical service respectively (12,20) and in a prospective study pointing out a 10 year survival rate of 83.4% (21). Briefly, the use of lithium disilicate restorations in fixed prosthodontics proved to be effective and reliable in the short and medium term (7).
The present *in vitro* study aimed at comparing the fracture resistance and mode of failure of CAD-CAM monolithic lithium disilicate single crowns (SCs) with different occlusal thickness cemented onto human molars.
The null hypotheses stated that there was no association between the occlusal thickness and either the fracture resistance [1] and the mode of failure [2] of CAD-CAM monolithic lithium disilicate SCs.

MATERIALS AND METHODS

Specimen preparation

Thirty human maxillary third molars extracted for periodontal reasons were used for the study. Teeth with caries and/or previous restorations were excluded; only sound teeth with similar (±1mm) bucco-lingual, mesio-distal and corono-apical dimensions were included in the study. Dental plaque, calculus and external debris were removed with an ultrasonic scaler. In order to simulate the oral environment, the teeth were stored in an incubator at 37 °C at 90% relative humidity until the execution of the mechanical tests.
Each tooth was embedded in a block of self-curing acrylic resin (Caulk Orthodontic Resin, Dentsply caulk, Milford, DE, USA) surrounded by a stainless steel cylinder with the long axis perpendicular to the base of the block, leaving 1 mm of the root exposed. In order to dissipate the heat generated during the polymerization of the resin, the specimens were continuously moistened with water spray. A thin layer of polyvinylsiloxane impression material (Flexitime, Heraeus Kulzer, Hanau, Germany) was applied on dental roots to simulate the periodontal ligament.
Each tooth was covered with a powder for digital scanning (Cerec Optispray, Sirona Dental, Salzburg, Austria) and three-dimensionally (3D) scanned by means of a laboratory optical digital scanner (GC Aadva Lab Scan, GC, Tokyo, Japan). The 3D shape of each tooth was digitized, so as to use it for the fabrication of CAD-CAM monolithic crowns (Fig. 1). Standardized tooth preparations were performed with high speed diamond rotary cutting burs under constant water cooling, according to the following geometry: 1 mm axial reduction, 0.7 peripheral rounded minichamfer shoulder

FIG. 1 Anatomy digitization: 3D scanning of the original anatomy of a specimen.

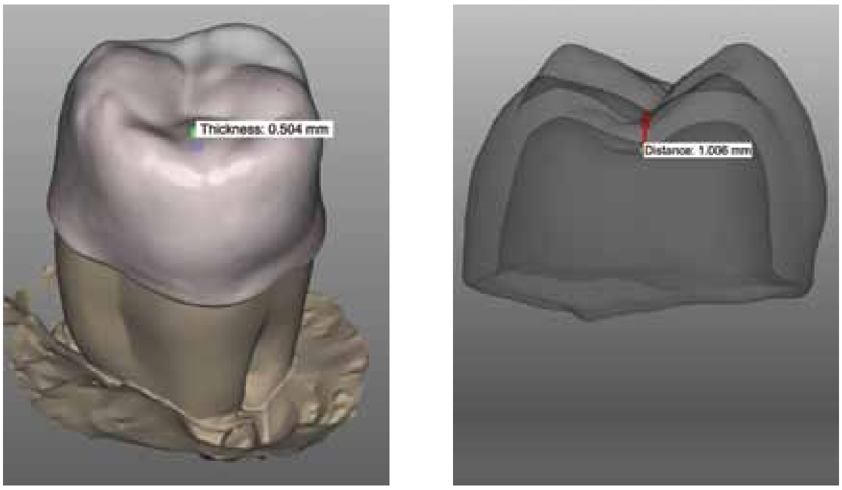

FIG. 2 CAD process: occlusal thickness and distance measurements.

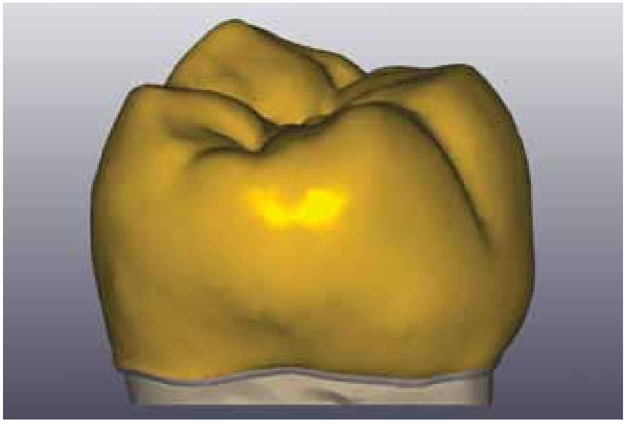

FIG. 3 CAD finalization: monolithic lithium disilicate single crown designed in accordance with the original digitized anatomy.

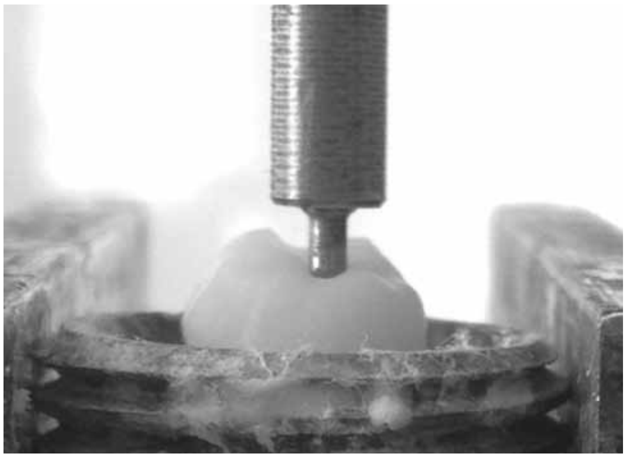

FIG. 4 Static load at fracture: axial load direction and application.

placed 0.5 mm above the cemento-enamel junction, 12° of total occlusal convergence; all preparation angles were rounded. The 30 specimens were randomly divided into 3 groups of 10 specimens each and different occlusal thickness preparations were performed as follows: 0.5 mm (group 1), 1.0 mm (group 2) and 1.5 mm (group 3).

As previously described, each abutment tooth was scanned and digitized and 30 monolithic lithium disilicate SCs were designed by means of a dedicated CAD software (Exocad DentalCAD, Exocad GmbH, Darmstadt, Germany). The restorations of group 1, 2 and 3 presented with an occlusal thickness of 0.5, 1.0 and 1.5 mm respectively (Fig. 2).

The monolithic lithium disilicate crowns were designed according to the original shape of each specimen (Fig. 3). Cement spaces of 70 and 50 µm were simulated at the level of the intaglio surface and of the minichamfer shoulder respectively.

After the CAD-CAM restorations were fabricated (IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein), the internal surface of each crown was etched with 5% hydrofluoric acid (IPS Ceramic Etching Gel, Ivoclar Vivadent) for 20 s; then, the specimens were thoroughly rinsed and dried; finally, the restorations were silanized with a universal single-component bonding agent (Monobond Plus, Ivoclar Vivadent) applied for 60 s on the intaglio surface. A dual cure self adhesive universal resin cement (G-Cem LinkAce, GC, Tokyo, Japan) was used to lute the restorations. The crowns were seated onto the abutment teeth with finger pressure and then 5 kg were applied onto each crown for 5 min by means of a dedicated cementation appliance. Cement excess was removed with a microbrush and each surface was light-cured for 40 s with a LED curing unit (Elipar S10, 3M ESPE, Seefeld, Germany). A layer of glycerin gel was applied on the margin of each crown to block oxygen inhibition and polymerization was completed for 40 s on each surface.

Load to fracture test

A universal loading machine (Triaxial Tester T400 Digital, Controls srl, Cernusco, Italy) was used to statically load the specimens. Load to fracture was performed using a 1.0 mm stainless steel hemispherical tip placed in the occlusal fossa. The experimental load was applied at a crosshead speed of 1 mm/min in a direction parallel to the longitudinal axis of the tooth (Fig. 4).
All the samples were loaded until fracture and the maximum breaking loads were recorded in Newtons (N) by a computer (Digimax Plus, Controls srl) connected to the loading machine. The failure mode was visually evaluated using a stereomicroscope at 10x magnification (Zeiss OpMi1, Zeiss, Oberkochen, Germany) and the fracture patterns were examined using a scanning electron microscope (SEM Jeol, Tokyo, Japan).

Statistical analysis

The recorded data were statistically analyzed with a dedicated software (SPSS 13.0, SPSS Inc., Chicago, IL, USA). The Kolmogorov-Smirnov test was used to verify the normality of data distribution. The fracture values were analyzed with the one-way ANOVA; in order to verify whether statistically significant differences were found among the experimental groups, the Fisher's Exact test with Bonferroni's correction was applied. In all the analyses the level of significance was set at α=0.05.

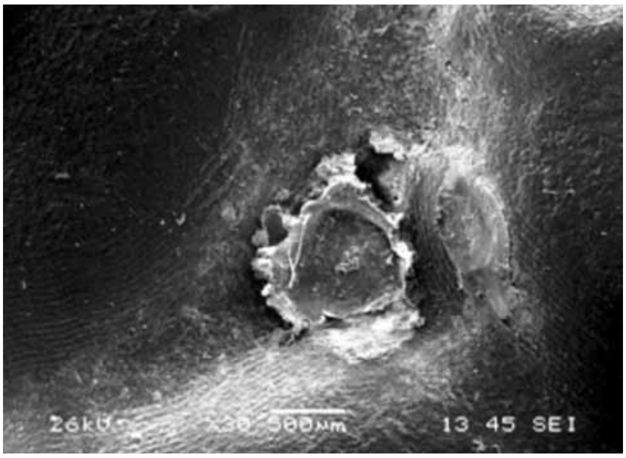

FIG. 5 Lithium disilicate crown chipping: SEM image of a cohesive microcrack of the lithium disilicate core in the occlusal region at level of the load application area.

RESULTS

In the present study, the survival rates of molar CAD-CAM monolithic lithium disilicate SCs were 10% in the experimental groups 1 and 3 and 50% in group 2.
The highest fracture resistance values were reported in group 2 while the lowest were noticed in group 1 (Table 1). The unrestorable fractures showed catastrophic adhesive failures of the SCs exposing either the cement layer and/or the dental surface (Fig. 5); conversely, the restorable

N	Group 1 (0.5 mm)		Group 2 (1.0 mm)		Group 3 (1.5 mm)	
	Fracture load (N)	Failure mode	Fracture load (N)	Failure mode	Fracture load (N)	Failure mode
1	434	U	1604	R	1810	U
2	1233	R	1712	R	1457	U
3	1042	U	1740	U	1610	U
4	395	U	1808	R	1627	U
5	636	U	1022	U	736	U
6	661	U	1455	U	1075	U
7	1331	U	1829	R	1713	U
8	812	U	817	U	1100	R
9	1008	U	1245	R	1828	U
10	718	U	1800	U	1439	U
Mean (±SD)	827 (±318.8)	-	1503 (±360.3)	-	1440 (±360.4)	-
%	-	R: 10% U: 90%	-	R: 50% U: 50%	-	R: 10% U: 90%

TAB. 1 Load at fracture (in Newtons) and failure patterns (R: restorable, U: unrestorable) of the experimental specimens.

fractures caused cohesive microcracks of the lithium disilicate cores in the occlusal region, particularly at level of the load application area (Fig. 6-8).
Statistically significant differences in the fracture strength ($p<0.05$) were pointed out only between group 1 and the other experimental groups (Table 2). As to the mode of failure, conversely, statistically significant differences were noticed between group 2 and the other experimental groups (Table 2).

DISCUSSION

According to the results of the present investigation, both null hypotheses were rejected, since there were statistically significant differences both in the fracture resistance [1] and the mode of failure [2] of CAD-CAM monolithic lithium disilicate SCs in relation to the occlusal thickness.
From a clinical viewpoint, the recorded cohesive occlusal microcracks can be considered repairable, since they could be polished intraorally without impairing function.
Monolithic lithium disilicate crowns showed higher fracture resistance than bilayered ones (16,17) and their wall and occlusal thicknesses influence the fracture strength of restorations (14,15).
Although several clinicians are proposing very conservative lithium disilicate restorations with ultrathin (i.e. up to 0.5 mm) occlusal thickness (7), the scientific evidences regarding their clinical reliability are lacking, mainly based on case reports, particularly in posterior areas. Most investigations reported that thicker lithium disilicate cores showed higher fracture strength and recent *in vitro* analyses demonstrated that an occlusal thickness of 1.0 mm allowed monolithic lithium disilicate crowns to withstand occlusal forces in the molar areas (14,15).
In accordance with these findings, the recorded fracture values of all the experimental groups exceeded both the physiological (50-250 N) and parafunctional (500-

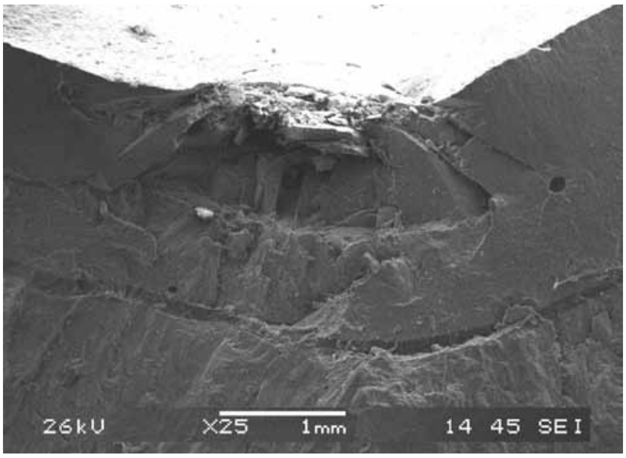

FIG. 6 Lithium disilicate crown failure: cross-sectional SEM image of a complete fracture of the lithium disilicate core starting from the load application area.

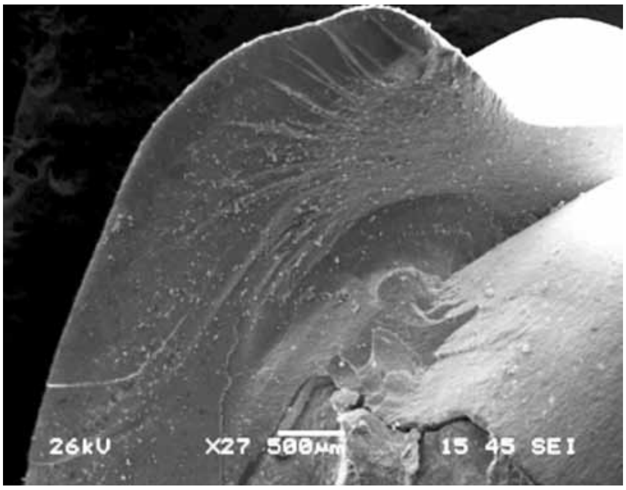

FIG. 7 Crack propagation: SEM detail of wake hackles deflecting from the load application area to the cusps and axial walls.

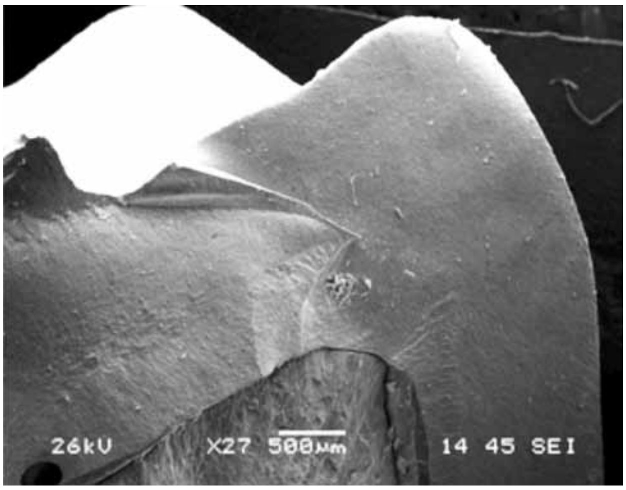

FIG. 8 Crack propagation: SEM detail of the deflection path of a crack inside a lithium disilicate crown.

	Fracture load Sig.	Mode of failure Sig.
Group 1 (0.5 mm)	A	a
Group 2 (1.0 mm)	B	b
Group 3 (1.5 mm)	B	a

TAB. 2 Statistical analyses: results of One-Way ANOVA and Fisher's Exact test with Bonferroni's correction (level of significance: $\alpha=0.05$); different letters indicate statistically significant differences.

800 N) occlusal loads in molar regions (22). Similarly to previous *in vitro* and *in vivo* investigations, the results of the present analysis suggested the possibility to reduce the occlusal thickness of monolithic lithium disilicate crowns up to a safety bound of 1.0 mm, reducing the invasiveness of the preparation and saving a valuable amount of dental tissues (7,9,12,14,15).

It is worth noticing that group 2 showed both the highest fracture resistance and the most favorable fracture pattern; consequently, in accordance with the manufacturer's instructions, it is possible to state that posterior lithium disilicate crowns should be designed with an occlusal thickness of 1.0 mm to guarantee the best mechanical performances under function and that thicker cores could be detrimental to the longevity of restorations. It could be speculated that this need is due to the fact that, being a filled glass-ceramic, lithium disilicate clinical performances are strongly related both to the type of resin cement and to the accuracy of adhesive procedures (4,23); as a consequence, the stress adsorbing capability of resin cements could not be entirely effective in the presence of bulk thicknesses of glass ceramics and this mechanical drawback could lead to intrinsic microcracks of lithium disilicate cores causing clinical failures.

Different factors could influence the results of static tests, such as specimen storage, die material, cementation technique and crosshead speed and this could explain the heterogeneity of data reported in the literature. Although fracture resistance was reported not to be influenced by luting agents (24), in the present study all the specimens were kept hydrated prior to mechanical testing and were cemented onto natural teeth with a dual-cure self-adhesive universal resin luting agent to simulate a real clinical situation. The formation of an adhesive "monoblock" (25) probably contributed to increase the resistance to fracture, letting the cement act as an elastic stress adsorber and compensating for the stiffness of the glassy component of lithium disilicate ceramic. Effective adhesion could strengthen the restorative system, allowing to dissipate the occlusal forces on the entire intaglio surface of the crowns; conversely, imperfect adhesion, voids and/or bubbles within the cement layer could negatively affect the effectiveness of adhesion (Fig. 9). As reported above, a reduced occlusal thickness (<1 mm) could not be sufficient to withstand such loads, whereas an excessive occlusal thickness (>1 mm) could reduce the stress adsorbing capability of the adhesive layer causing microcracks on the occlusal surface, because of both the direct application of forces and the increased distance to the cement layer. Similarly to previous investigations, the samples were experimentally fractured at a crosshead speed of 1 mm/min.

Although dynamic testing could give information about fatigue behavior, static axial load tests still represent the first step to evaluate the fracture resistance of

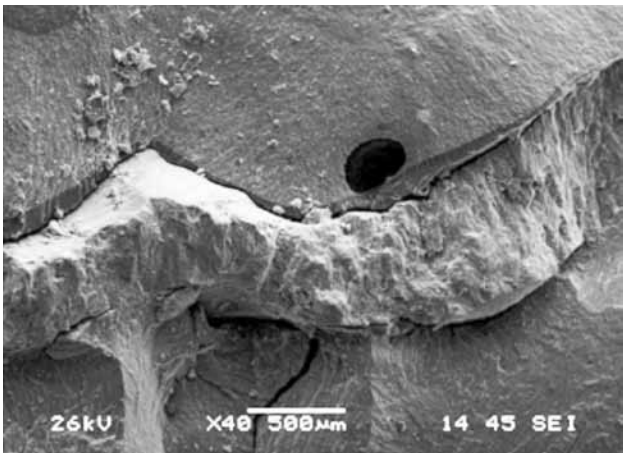

FIG. 9 Adhesive layer: SEM detail of an air bubble in the cement layer. Imperfect adhesion could contribute the the onset of mechanical failures reducing the stress adsorbing capability of the adhesive layer.

dental materials (26); however, such an approach would notify about the ultimate strength of materials in order to optimize the geometry of restorations but it is worth remembering that clinical failures mainly occur because of fatigue. As a consequence, the results obtained with static analyses have to be integrated with those achieved from dynamical tests. Recent *in vitro* investigations reported that monolithic lithium disilicate crowns proved to be more resistant than bilayered ones after aging and mechanical cycling (16,17).

It is not possible to extend laboratory data directly to clinical guidelines, since the clinical scenario is never completely replicated by *in vitro* tests (27). Consequently, the results of the present *in vitro* study have to be clinically validated, since only a static vertical load was evaluated.

CONCLUSIONS

Within the limitations of the present *in vitro* investigation, the following conclusions can be drawn:

1. the occlusal thickness of CAD-CAM monolithic lithium disilicate crowns influenced both the fracture resistance and the mode of failure of the restorations;
2. the occlusal thickness of CAD-CAM monolithic lithium disilicate crowns can be reduced up to a lower bound of 1.0 mm keeping a sufficient strength to withstand occlusal loads;
3. CAD-CAM monolithic lithium disilicate crowns showed sufficient fracture resistance to be used in molar regions but not in an ultrathin configuration (0.5 mm).

As it agrees with the results of previous studies, the present *in vitro* research can be considered a confirmative investigation on the possibility to use CAD-CAM monolithic lithium disilicate crowns in posterior regions with occlusal thickness in accordance with the manufacturers' instructions.

Further clinical investigations will be necessary to validate the results of the present study under functional loading.

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