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RESEARCH AND EDUCATION

Fracture resistance of lithium disilicate restorations after endodontic access preparation: An in vitro study

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ABSTRACT

Statement of problem. Endodontic access preparation through a lithium disilicate restoration is a frequently encountered clinical situation. The common practice of repairing the accessed crown with composite resin may result in a weakened restoration.

Purpose. The purpose of this in vitro study was to determine the effect of endodontic access preparation on the fracture resistance and microstructural integrity of monolithic pressed and monolithic milled lithium disilicate complete coverage restorations.

Material and methods. Twenty monolithic pressed (IPS e.max Press) and 20 monolithic milled (IPS e.max CAD) lithium disilicate restorations were fabricated. Ten of the pressed and 10 of the milled crowns were accessed for a simulated endodontic treatment and subsequently repaired by using a porcelain repair system and composite resin. All specimens were submitted to cyclic loading and then loaded to failure. Force data were recorded and analyzed with 2-way ANOVA followed by a post hoc test (Sidak correction) to indicate significant differences among the groups (α=.05). A Weibull analysis was also performed for each group. Eight (4 pressed and 4 milled) additional restorations were fabricated to complete a scanning electron microscope (SEM) analysis and evaluate the surface damage created by the endodontic access preparation.

Results. A statistically significant difference (*P*=.019) was found between the pressed intact and pressed repaired restorations and between the pressed intact and milled repaired restorations (*P*=.002). Specimens that were examined with an SEM showed edge chipping involving primarily the glaze layer around the access openings.

Conclusions. Endodontic access preparation of lithium disilicate restorations resulted in a significantly reduced load to failure in the pressed specimens, but not in the milled specimens. (J Prosthet Dent 2015;114:580-586)

Any tooth planned to receive a complete coverage restoration should be tested for pulp vitality before proceeding with the tooth preparation. Nevertheless, endodontic-related complications may arise after the placement of the definitive restoration, with a reported incidence as high as 15%.[1-4] For such patients, endodontic treatment through the complete coverage restoration can be challenging. First, fewer clinical landmarks are available to orientate the pulp chamber, and clinical judgment must be used to design the appropriate access opening. Second, during access preparation, a significant amount of the dentin foundation will have to be removed, resulting in a significantly weaker foundation; this makes it difficult to assess whether it is adequate to support the crown. In addition, endodontic access preparation through ceramic crowns creates 2 additional specific concerns. First, ceramics are poor conductors of heat; therefore, heat formation during endodontic access preparation is hard to control and may generate residual stresses and stress gradients.[5] Second, access and instrumentation with rotary instruments may induce

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Clinical Implications

A porcelain repair of an endodontically accessed e.max crown, regardless of the method of fabrication (pressed or milled), can provide a serviceable restoration when no other damage is visually detected on the surface of the accessed restoration.

microcrack formation, fracture initiation, and ceramic failure.[5]

The procedure of gaining access to the pulp chamber through porcelain jacket crowns was first described in 1962.[6] Since then, diamond rotary instruments[7-10] and, recently, airborne-particle abrasion[11] have been proposed as access methods for ceramic crowns. Teplitsky and Sutherland[8] evaluated the effect of endodontic access opening on alumina core crowns (Cerestore) and reported chips and roughness on the external outline form of all access openings. Sutherland et al[7] examined the effect of the same procedure on Dicor crowns and reported crown fracture (4.8%) and crazing (16.7%). The higher crystalline content of lithium disilicate crowns (70 vol%, compared with about 55 vol% of other glass ceramic systems)[12] makes penetration of those crowns more difficult.

After the successful completion of endodontic treatment, the definitive restorative protocol is based on clinical judgment and consists of either managing the access opening with a restorative material or replacing the entire restoration. Little evidence supports 1 treatment option over the other; however, patients usually opt for the first option for financial reasons. Even though the repair procedure for ceramics and its associated mechanisms have been adequately described,[13-20] the resistance to fracture of the repaired ceramic crown has not been adequately investigated.

The fracture resistance of ceramic crowns before and after endodontic access preparation and subsequent repair has been examined in 2 studies. Wood et al[21] examined the effect of endodontic access preparation on alumina and zirconia core ceramic crowns and concluded that the procedure resulted in a significant decrease in the strength of zirconia specimens, but not in alumina specimens. Qeblawi et al[22] evaluated the effect of simulated endodontic access preparation on the failure load of milled lithium disilicate crowns (IPS e.max CAD) and concluded that an efficient rotary instrument caused less damage to the restoration, with higher failure loads, and also protected the integrity of the adhesive interphase. However, a limitation of this study was that the specimens were not cyclically loaded before testing. Thermomechanical fatigue loading[23] in a simulated oral environment has been found to significantly affect the fracture resistance of ceramics and leads to more clinically meaningful results.[24-27] In addition, this study only examined the effect of access preparation on milled lithium disilicate restorations. Pressed lithium disilicate restorations have not yet been studied, even though they are becoming a commonly used restorative treatment option.[28,29]

The purpose of this in vitro study was to evaluate how endodontic access preparation and subsequent repair may alter the fracture resistance of pressed and milled monolithic lithium disilicate crowns after fatigue testing (cyclic loading). Additionally, this study aimed to examine the damage that occurred to the crowns once an endodontic access opening was completed. The null hypothesis was that no difference would be found in the mean failure load values between the intact and the accessed (and repaired) crowns, regardless of their fabrication technique (pressed or milled).

MATERIAL AND METHODS

A wax pattern was fabricated to simulate a mandibular first molar ceramic complete crown preparation according to the manufacturer's recommendations for IPS e.max (Ivoclar Vivadent AG) posterior crowns. The dimensions were a 12-degree total occlusal convergence, an 8-mm diameter, a 4-mm preparation height, a uniform reduction of 1.5 mm on the axial and occlusal walls, and a 1-mm circumferential shoulder finish line with a rounded axiogingival angle. The pattern was subsequently sprued, invested, and cast with cobalt-chromium alloy (Vitallium; Dentsply Intl) to obtain a master die. Forty identical dies were fabricated to replicate the master die with a highly filled epoxy resin (Viade Products Inc) reported to have a modulus of elasticity similar to human dentin.[21,30-32] The dies were then divided into 2 groups, P (pressed) and M (milled), with each group consisting of 20 specimens.

For group P, a standardized waxing was completed on each die with a uniform thickness of 1.5 mm. All copings were sprued and invested (IPS PressVEST Speed; Ivoclar Vivadent Inc) following the manufacturer's recommendations, and 20 heat-pressed monolithic crowns were produced by using a pressing furnace (Vario Press 300; Zubler USA Inc). One glaze firing cycle was completed. For group M, a wax coping with the same dimensions as for group P was fabricated and subsequently scanned with a computer-aided design and computer-aided manufacturing (CAD/CAM) system, which used 3-dimensional laser technology (CARES Scan CS2; Straumann AG) with the associated software (CARES Visual 8.0; Straumann AG). The data obtained were used to produce 20 identical milled monolithic lithium disilicate restorations from IPS e.max CAD blocks of high translucency. One combined crystallization/glaze firing cycle was completed. A dual-polymerizing resin based system for adhesive luting (Variolink II; Ivoclar Vivadent Inc) was used to cement all restorations on their respective dies. A uniform force of 50 N was applied during light polymerization of the cement. After cementation, all specimens were stored in a humid saline environment at room temperature for 3 weeks.

The specimens from each group were then further divided into 2 subgroups, with a total of 10 specimens in each of the following subgroups: intact pressed crowns (PI), pressed crowns with a repaired standardized endodontic access preparation (PR), intact milled crowns (MI), and milled crowns with a repaired standardized endodontic access preparation (MR). For groups PR and MR, a standardized conservative endodontic access preparation with a diameter of 3.5 mm was completed. The desired access opening was marked on the first specimen; after the preparation was completed, a plastic template was fabricated and subsequently used to delineate the access openings on all the crowns from groups PR and MR. All endodontic access preparations were performed by 1 clinician (D.B.) using an electric handpiece at 200 000 rpm and applying the same amount of force under copious water irrigation. The selected rotary instrument for this procedure was a coarse-grit (126 μm), tapered, round-end chamfer diamond (ZR6856.016; Komet), which has been ranked as the most efficient for cutting through lithium disilicate material.[22] For each access opening, a new rotary instrument was used. Immediately after completion of all endodontic access preparations, the restorations were repaired with a porcelain repair system (Intraoral Repair Kit; Bisco Inc) and a direct nanocomposite resin restoration (Filtek Supreme Ultra Universal Restorative; 3M ESPE). The occlusal portion of the repair was made level with the adjacent lithium disilicate material, and the interface was lightly smoothed with a rubber wheel under water irrigation.

All 40 specimens were submitted to a fatigue test that consisted of cyclic loading in a dry state between minimum and maximum loads of 50 and 250 N for a total of 250 000 cycles, corresponding to 1 year of clinical service.[33] A servo hydraulic testing machine was used (858 Mini Bionix II; MTS Systems Corp). The cyclic loading had a force profile in the form of a sine wave at a loading frequency of 1.6 Hz and an axial loading direction. The specimens were subsequently positioned in a universal testing machine (Instron Corp) and loaded with a stainless steel piston along their long axis at a 0.2 mm/min crosshead speed until failure. The diameter of the loading piston was 6 mm along its long axis, and its end was machined to accommodate a 0.5-m radius of curvature, thus eliminating high-contact stresses.[26] The end of the piston was directed toward the center of the occlusal surface of each crown; for the repaired crowns, it contacted both the composite resin repair and the surrounding lithium disilicate material. Room temperature was maintained throughout the mechanical testing. A 1% drop in the compressive load and/or visualization of crack formation was designated as failure of the restoration. Force at the time of failure was recorded in newtons (N).

Table 1. Descriptive statistics of load to failure (mean ±SD) for 4 groups

Variable	Pressed Intact	Pressed Repaired	Milled Intact	Milled Repaired
Sample size	10	10	10	10
Load to failure (N)	1901 ±349	1429 ±384	1573 ±267	1297 ±329
Minimum (N)	1479	1128	1327	882
Maximum (N)	2554	2283	2094	1835
Kolmogorov-Smirnov[a]	P=.200	P=.069	P=.182	P=.200
Levene test[b]	P=.751			

[a] Test for normal distribution ($P \leq .05$).
[b] Test for homogeneity of variances among groups ($P \leq .05$).

After collecting the force data for all 40 specimens, a statistical analysis was performed with statistical software (SPSS Statistics v19.0; SPSS Inc). Fracture strength was the dependent variable; the presence of a repaired endodontic access preparation and the method of fabrication (pressed vs milled) were the independent variables. The data were tested for normality with the Kolmogorov-Smirnov test and for homogeneity of variances with the Levene test. ANOVA followed by a post hoc test (Sidak correction) was used to indicate significant differences among the groups (α=.05). A Weibull analysis was also performed with life data analysis software (Weibull++; ReliaSoft) to calculate the Weibull parameters (modulus and characteristic failure load) and therefore compare the mechanical reliability of the 4 groups. The same software was used to compare the load level of each group corresponding to a 5% probability of failure.

Eight additional specimens (4 pressed, 4 milled) were also fabricated using the same methodology as the 1 followed for the specimens belonging to the initial groups P and M. Those specimens were accessed for an endodontic treatment using the same standardized protocol, then coated with gold and examined under SEM. If the original crowns had been used for this SEM examination, then the sputter coating could have interfered with the porcelain repair protocol that would follow. Photomicrographs were obtained to serve as an example of the damage caused to the restorations by the procedure.

RESULTS

The load-to-failure data (mean ±SD and minimum and maximum load values) are listed in Table 1. The mean load to failure values ranged from 1297 N (group MR) to 1901 N (group PI). The maximum load was observed in group PI (2554 N) and the minimum load in group MR (882 N). Table 2 lists the ANOVA according to type of restoration (pressed or milled) and condition (intact or

Table 2. ANOVA for load to failure according to type of restoration (pressed or milled) and condition (intact or repaired)

Source	Type III Sum of Squares	*df*	Mean Square	F	*P*
Corrected Model	2.03E+06	3	6.76E+05	6.035	.002
Intercept	9.61E+07	1	9.61E+07	857.418	<.001
Type	5.30E+05	1	5.30E+05	4.734	.036
Condition	1.40E+06	1	1.40E+06	12.509	<.001
Type × Condition	9.66E+04	1	9.66E+04	0.862	.359
Error	4.03E+06	36	1.12E+05		
Total	1.02E+08	40			
Corrected Total	6.06E+06	39			

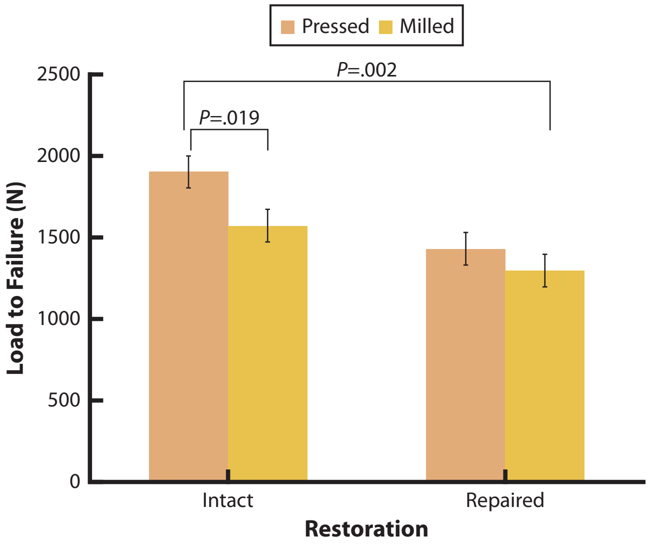

Figure 1. Load to failure (N) according to type of restoration (pressed or milled) and condition (intact or repaired).

Table 3. Weibull parameters (modulus and characteristic load) for 4 groups

		95% Confidence Interval	
Group	**Estimate**	**Upper**	**Lower**
Weibull modulus			
Pressed Intact	5.9	9.4	3.7
Pressed Repaired	3.9	6.1	2.5
Milled Intact	6.3	9.9	4.0
Milled Repaired	4.5	7.3	2.8
Characteristic load (N)			
Pressed Intact	2044	2285	1830
Pressed Repaired	1572	1860	1329
Milled Intact	1685	1870	1517
Milled Repaired	1421	1643	1229

Table 4. Point estimates corresponding to 5% probability of failure for 4 groups

		95% Confidence Interval	
Group	**Load Estimate (N)**	**Upper Lower**	**Lower**
Pressed Intact	1239	1652	929
Pressed Repaired	737	1127	483
Milled Intact	1050	1377	802
Milled Repaired	738	1086	501

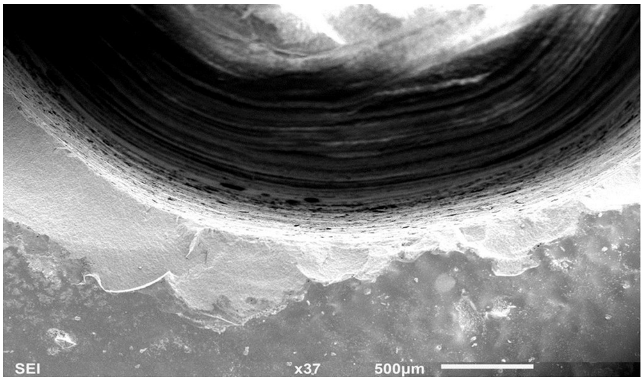

Figure 2. Scanning electron micrograph of accessed pressed crown showing edge chipping extending radially around access opening, original magnification ×37. Chipping primarily involved glaze layer, but also extended into superficial portion of lithium disilicate material.

repaired). The type of restoration (*P*=.036) and condition (*P*≤.001) were both statistically significant. Figure 1 shows the comparisons among the 4 groups with Sidak adjustment for multiple comparisons. This indicates that the fracture strength (mean ±SD) of pressed restorations 1665 N (±431 N) was statistically higher than that of the milled ones 1435 N (±324 N) and that intact restorations showed a mean of 1737 N (±346 N) that was statistically higher than the repaired ones 1362 N (±354 N). Figure 1 shows the comparisons among the 4 groups with Sidak adjustment for multiple comparisons. A significant difference between groups PI and PR (*P*=.019) and between groups PI and MR (*P*=.002) was noted.

The Weibull statistical analysis of the fracture load data is summarized in Table 3. The Weibull moduli for both intact groups (PI and MI) were higher than those of the repaired groups (PR and MR). The characteristic load for group PI was the highest among all groups. However, none of those differences was statistically significant in that because the 95% confidence intervals overlapped. Table 4 summarizes the point estimates and 95% confidence intervals corresponding to a 5% probability of failure. Group PI had the highest load value (1239 N) and group MR the lowest (738 N).

All additional specimens that were examined under SEM showed edge chipping extending radially from the openings associated with the endodontic access preparations. Chipping primarily involved the glaze layer but also extended up to 0.3 mm into the occlusal portion of the lithium disilicate material on both pressed and milled crowns (Fig. 2). One of the chips on a milled crown extended as a radial crack from the access up to 0.5 mm from the proximal wall of the restoration (Fig. 3) and was

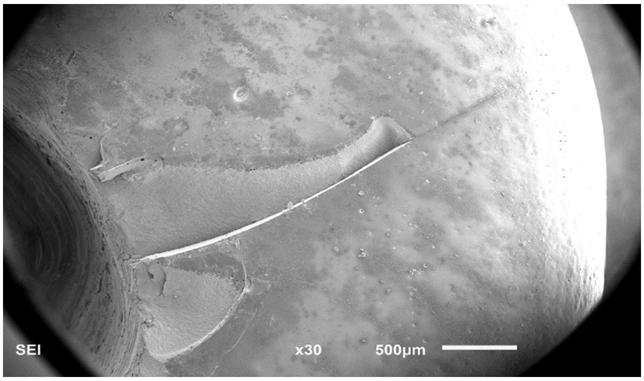

Figure 3. Scanning electron micrograph of milled crown showing radial crack formation extending close to proximal wall of restoration, original magnification ×30.

readily detectible by visual inspection. No other radial cracks or microcracks within the internal microstructure of the material associated with the walls of the endodontic preparations were noted. The cross section of the internal surface of the milled crowns, as shown through the internal walls of the access preparations, appeared more irregular than that of the pressed crowns (Figs. 4, 5).

DISCUSSION

The null hypothesis of the study that no difference would be found in the mean load to failure of the intact and the repaired crowns was rejected for the pressed restorations. However, the results of this study failed to support the rejection of the null hypothesis for the milled restorations. This finding can be attributed to the higher fracture resistance values obtained for the pressed intact crowns than for the milled intact crowns. The repair of the crowns subjected to endodontic access preparation did restore the weaker milled crowns close to their original strength but failed to do so for the stronger pressed crowns. These results are comparable with those reported by Wood et al,[21] who found a significant decrease in strength for the repaired zirconia crowns, but not for the repaired alumina crowns. The hypothesis is that the stronger a material is when inserted in the mouth, the more difficult it will be to maintain these high mechanical properties when it is subjected to a damaging clinical procedure.

Another factor to consider is the difference in the microstructure between the 2 groups of restorations. The manufacturer states that the lithium disilicate crystal size in the pressed restorations is approximately 3 to 6 µm in length, whereas in the milled ones it is approximately 1.5 µm. The smaller crystal size contained in the milled restorations creates a larger contact surface, which may facilitate the formation of a better bond between the lithium disilicate and the repair material. Thus, the repaired milled restorations may achieve high loading values that can even approximate those of the intact milled group.

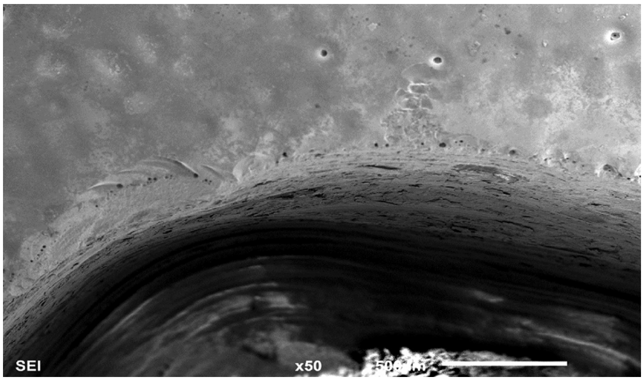

Figure 4. Scanning electron micrograph of accessed milled restoration, original magnification ×50. Internal microstructure reveals irregularities.

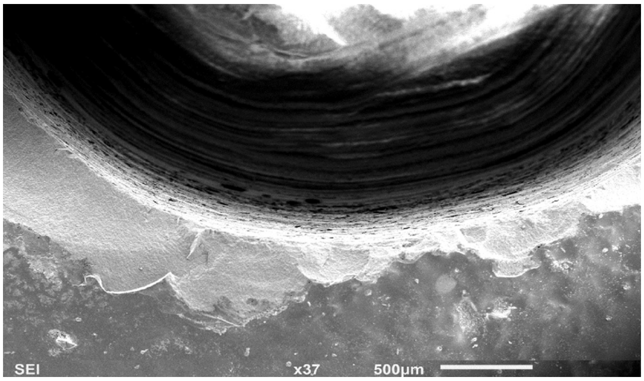

Figure 5. Scanning electron micrograph of accessed pressed restoration, original magnification ×37. Internal microstructure appeared more homogeneous than that of milled restorations.

Pressed lithium disilicate restorations have been reported by the manufacturer to have higher fracture resistance compared with milled restorations, and this was supported by the findings of the present study. However, this difference was not statistically significant, indicating that the method of fabrication is not a critical factor for the mechanical properties of the material. Both types of restorations had significantly higher failure loads (1901 N and 1573 N) than the average occlusal force of 720 N that is typically applied on a molar.[34] Most importantly, the mean failure loads for both repaired groups were also above the average occlusal force, indicating that repaired lithium disilicate restorations can still be serviceable.

The Weibull analysis showed that endodontic access preparation and subsequent repair affected the reliability of both pressed and milled restorations. The Weibull moduli for both intact groups were higher than those of the repaired groups, indicating higher material homogeneity and therefore lower probability of failure for those specimens. This was an expected finding, since the procedure of accessing the crown would introduce more flaws in the material. Since the strength of dental ceramics is primarily flaw-dependent,[5] any procedure that introduces microcracks within the internal structure of the material could accelerate the long-term failure of the material. The Weibull analysis included comparing the characteristic load for the 4 groups, which corresponds to the load value below which 63.2% of the specimens are predicted to fail. Specimens belonging to group PI were likely to fail in loads that were much higher than the loads for the other 3 groups; however, none of these differences was statistically significant. Further analysis of the load estimates and 95% confidence intervals corresponding to a 5% probability of failure was conducted for all groups. A comparison at this level may result in some loss of statistical power but provides more clinically relevant data. The results showed a significant difference in the fracture resistance before and after the endodontic procedure. The load corresponding to a 5% probability of failure was almost the same for both repaired groups (737 N for repaired pressed and 738 N for repaired milled restorations). This finding indicates that pressed restorations may be initially stronger than milled restorations; however, once they are subjected to a damaging clinical procedure such as endodontic access preparation, their fracture resistance will drop to the same levels as those of the milled restorations, even though the latter were initially weaker.

A final factor that needs to be considered in the attempt to present a possible repair protocol for lithium disilicate restorations is the feasibility of bonding the repair material with lithium disilicate.[13-20] To our knowledge, only 1 published study investigates the effect of different surface pretreatments on the bond strength between lithium disilicate and composite resin repair material.[14] The authors concluded that treating IPS e.max CAD surfaces with hydrofluoric acid and silane before repair was better than airborne-particle abrading the ceramic surface[20]; however, this study did not include any pressed surfaces. Since the repair of ceramic restorations is a commonly encountered clinical situation and its occurrence will only increase in the future, more studies are needed to establish the most appropriate protocol for restoring the coronal seal.

In our study, the specimens were round and symmetric, without the incline planes and the shape variations that exist in natural teeth. However, even in natural teeth, loading should follow an axial rather than an oblique direction; therefore, the absence of cusps and occlusal anatomy on the specimens was not considered to be a limitation of the study. However, different loading directions that may occur if proper adjustments are not completed may have a different effect on the results.

Cyclic loading under dry conditions is 1 of the limitations of this study. While wet storage and dry cyclic loading reduce the failure loads of ceramic restorations, the presence of water during cyclic loading has been reported to produce failure loads that are more meaningful from a clinical standpoint. The specimens were also stored in saline, whereas the dynamic oral environment may have a further negative effect on the aging of the ceramic. Even though this study followed as closely as possible the recommendations for testing ceramics as proposed by Kelly[26] and Kelly et al,[27] some improvements can still be suggested, including cyclic loading under wet conditions. Future studies could evaluate the effect of endodontic access preparation and subsequent repair on bilayer lithium disilicate crowns. Finally, SEM analysis of a larger group of accessed crowns could reveal more detailed information regarding the type and extent of damage to the crowns during endodontic treatment.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions can be drawn:

1. Endodontic access preparation of lithium disilicate restorations resulted in a significant decrease in the fracture resistance of the pressed (IPS e.max Press) restorations, but not in the milled (IPS e.max CAD) restorations.
2. The fracture resistance of intact pressed lithium disilicate restorations was higher than that of intact milled lithium disilicate restorations.
3. Endodontic access preparation resulted in edge chipping around the access openings of all crowns and primarily involved the glaze layer (IPS e.max Ceram; Ivoclar Vivadent Inc).

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