RESEARCH

Evaluation of the fracture strength of different CAD/CAM inlay restorations after accelerated aging*

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ABSTRACT

Evaluation of the fracture strength of different CAD/CAM inlay restorations after accelerated aging

Background: The purpose of this study was to compare the fracture resistance of inlay restorations manufactured by computer aided design/computer aided manufacturing (CAD/CAM) using different materials after accelerated artificial aging.

Materials and Methods: Class I inlay preparations were made for 40 mandibular molar teeth. The teeth were allocated into four groups (n=10) according to the type of manufacturing material used: feldspathic-ceramic (CEREC blocks); leucite-based glass-ceramic (IPS Empress CAD); resin nano-ceramic (Lava Ultimate); and a control (intact teeth). After obtaining digital impressions, restorations were designed and milled with CAD/CAM. Inlay restorations were cemented to the inlay cavities using a dual-polymerizing resin cement (Rely X Ultimate) and stored in distilled water at 37°C for a week. All the samples were then exposed to accelerated ultraviolet aging for 300 hours. Finally, a compressive load was applied to the samples until fracture. Statistical analysis was conducted using One-Way ANOVA and the Tukey HSD test (α=0.05).

Results: The mean fracture strength values of the groups were; Control (1555.3±412.2 N)> Lava Ultimate (1525±394N)>IPS Empress CAD (1364.3±545.6N) > CEREC(1231.9±412.2N), respectively. However, there was no statistically significant difference in mean fracture strength among different inlay restoration groups (P>0.05). Fifty percent of the both CEREC and IPS Empress CAD groups and 60% of the Lava Ultimate group showed reparable fractures.

Conclusion: The type of material used did not influence the fracture strength of inlay-restored molar teeth and inlay restorations did not weaken the strength of the restored teeth. Therefore, all of the tested materials are suitable for use in the posterior region.

KEYWORDS

CAD/CAM, ceramic, fracture strength, inlay, resin nano-ceramic

ÖZ

Farklı CAD/CAM inlay restorasyonların yapay yaşlandırma sonrası kırılma dayanımlarının incelenmesi

Amaç: Bu çalışmanın amacı, farklı materyaller kullanılarak bilgisayar destekli tasarım/bilgisayar destekli üretim (CAD/CAM) ile üretilen inley restorasyonların hızlandırılmış yapay yaşlandırma sonrasında kırılma direncini karşılaştırmaktır.

Gereç ve Yöntemler: Kırk adet mandibular molar dişe sınıf I inlay preparasyonu yapıldı. Dişler, kullanılan malzeme tipine göre dört gruba (n = 10) ayrıldı: feldspatik-seramik (CEREC Blocks); lösit bazlı cam seramik (IPS Empress CAD); rezin nano-seramik (Lava Ultimate); ve kontrol (sağlam dişler). Dijital ölçüler elde edildikten sonra restorasyonlar CAD/CAM ile tasarlandı ve üretildi. İnlay restorasyonlar, dual polimerize bir rezin siman (Rely X Ultimate) kullanılarak inlay boşluklarına simante edildi ve bir hafta boyunca 37°C'de distile su içinde saklandı. Tüm örnekler daha sonra 300 saat boyunca hızlandırılmış ultraviyole yaşlandırmasına maruz bırakıldı. Son olarak, kırılıncaya kadar örneklere bir sıkıştırma yükü uygulandı. İstatistiksel analiz Tek Yönlü ANOVA ve Tukey HSD testi (α= 0,05) kullanılarak yapıldı.

Bulgular: Grupların ortalama kırılma dayanımları sırasıyla şu şekildedir: Kontrol (1555,3±412,2 N) > Lava Ultimate (1525±394 N) > IPS Empress CAD (1364,3±545,6 N) > CEREC (1231,9±412,2 N). Ancak grupların ortalama kırılma dayanımları arasında istatistiksel bir fark bulunamadı (P>0,05). CEREC ve IPS Empress CAD gruplarının %50'si ve Lava Ultimate grubunun %60'ı tamir edilebilir kırık tipi sergiledi.

Sonuç: Kullanılan materyal tipi, inley ile restore edilmiş molar dişlerin kırılma direncini etkilememiştir ve inley restorasyonlar restore edilen dişlerin gücünü zayıflatmamıştır. Bu nedenle, test edilen tüm materyaller posterior bölgede kullanılabilir.

ANAHTAR KELİMELER

CAD/CAM, seramik, kırılma dayanımı, inley, rezin nano-seramik

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Inlay restorations are used to restore damaged posterior teeth due to caries, trauma, or cavity preparation.[1] A number of materials, including amalgam, gold, composites, or ceramics are used for inlays; however, with the increasing demand for esthetics and biocompatibility of dental restorations, both dentists and patients are becoming more interested in tooth-colored materials.[2] Inlays can be manufactured using the computer-aided design/computer-aided manufacturing (CAD/CAM) technique.[3] With the aid of CAD/CAM, inlays can be fabricated directly in the mouth or extraorally using a model.[4] Furthermore, industrially manufactured ceramic or composite blocks have been introduced into dentistry to improve the mechanical properties of restorative materials.[4-6] Industrially processed ceramics or composites have resulted in a remarkable reduction in the numbers of voids, flaws, and cracks in comparison with those that are laboratory produced.[7] It has also been reported that restorations produced by using CAD/CAM have high color stability, excellent marginal adaptation, clinically acceptable wear, and favorable bonding to adhesive resins.[6, 8]

Although ceramics are used for dental restorations, a major problem is their clinical failure in the posterior region.[9] Rapid changes in thermal, physical, and chemical conditions may induce fatigue and fracture of ceramic restorations.[1,10] In the aqueous environment, subcritical crack growth develops, propagates through the material to the outer surface, and finally leads to fracture.[11] Hence, new approaches to the development of CAD/CAM blocks are being considered to combine the advantages of both ceramics and composite resins.[12,13] Resin nano-ceramics are made of nano-ceramic particles inserted in a highly cured resin matrix.[14] These materials have gained popularity due to their high flexural[13] and fracture strength[15], high strength of bonding to resin cement[16], smooth surface finish[17], and favorable mechanical fatigue degradation .[12]

Fracture resistance is one of the most critical factors influencing the survival rate of inlays, and the debate is currently ongoing on whether ceramics or composite resins should be selected for CAD/CAM inlays.[14] It is a matter of curiosity that the resin nano-ceramic material would exhibit better fracture resistance than those of the ceramic materials or not.

The purpose of this study was to compare the fracture resistance of inlay restorations manufactured with different materials using CAD/CAM after artificial accelerated aging. The null hypothesis was that there would be no difference in fracture strength values among the groups tested.

MATERIALS AND METHODS

Human teeth were used in this study, and this study was ethically conducted according to the Helsinki Declaration (World Medical Association). The local ethics committee approval was obtained for this study from İstanbul Aydin University Faculty of Dentistry Clinical Research Ethics Committee. Forty sound, freshly extracted human molar teeth that were of similar size and free of caries were used in this study. After the removal of soft tissue and calculus, the teeth were kept in 0.5% chloramine T at room temperature for one week. The teeth were then embedded in self-polymerizing acrylic resin blocks (Meliodent, Heraeus Kulzer GmbH, Hanau, Germany) up to 2 mm below the cemento-enamel joint line to simulate the alveolar bone level. Standard Class I inlay cavities were prepared using inlay preparation diamond burs (Intensiv Ser Inlay Set; Swiss Dental Products, Viganello-Lugano, Switzerland) under water cooling by the same investigator. The dimensions of the cavities were measured continuously during the cavity preparation with a digital caliper (Mitutoyo Corp., Kawasaki, Japan) and the depth of the cavity was measured with a periodontal caliper. The cavities had a mesiodistal length of 6 mm, a buccolingual width of 3 mm, a depth of 2 mm, and a convergence angle of 6 degrees.

The teeth were separated into 4 groups (n=10 each) according to material type: intact teeth with no cavity preparation (control); teeth restored with feldspathic-ceramic blocks (CEREC blocks, Sirona, Bensheim, Germany); teeth restored with leucite-based glass-ceramic blocks (IPS Empress CAD, Ivoclar Vivadent, Schaan, Liechtenstein); and teeth restored with resin nano-ceramic blocks (Lava Ultimate, 3M ESPE, St Paul, MN, USA). The information about the composition of the materials can be found in Table 1.

Table 1.

Materials used in this study

Product	Manufacturer	Type	Composition
CEREC Blocks	Sirona GmbH, Germany	Fine particle feldspathic glass-ceramic	SiO_2, Al_2O_3, Na_2O, K_2O, CaO, TiO_2, other oxides, pigments
IPS Empress CAD	Ivoclar Vivadent, Liechtenstein	Leucite-based glass-ceramics	SiO_2, Al_2O_3, Na_2O, K_2O, other oxides, pigments
Lava Ultimate	3M ESPE, USA	Resin nano-ceramic	Fillers (80%): 20nm silica particles; 4-11nm zirconia particles; 0.6–10m nanoparticle clusters Matrix: Bis-GMA, Bis-EMA, UDMA, TEGDMA

**Acording to manufacturers*

Prepared inlay cavities were coated with a special titanium dioxide spray (CEREC Optispray, Sirona) and digital impressions were taken using the bluecam camera of the CAD unit (CEREC Connect AC). The restorations were designed using the software program (CEREC SW 4.0; Sirona) of the CAD unit. The cement thickness (90 μm) was recorded in the software program and restorations were then milled from the respective blocks using the milling unit (CEREC MC XL).

A universal self-etch adhesive (Single Bond Universal, 3M ESPE) was exerted to the inlay cavities for 20 s and thinned gently with air spray for 5 s. The inlay restorations were adhesively cemented to the inlay cavities using a dual-polymerizing resin cement (Rely X Ultimate, 3M ESPE) according to the manufacturer's instructions. A glycerin gel was applied to the margins of the inlay restorations to prevent the formation of an oxygen inhibition layer, and the restorations were then light-cured for 20 s. All of the restorations were polished with a handpiece for 10 s at a speed of 10,000 rpm under water cooling by the same investigator using a series of coarse-, medium-, and fine-silicon carbide rubbers (Astropol+Astrobrush, Ivoclar Vivadent). The samples were then kept in distilled water in the dark at 37°C for one week.

All of the specimens were aged using an accelerated artificial aging machine (Atlas UV 2000; Atlas Electronic Devices, Chicago, IL, USA). The aging process was performed by exposing the specimens to water spray, temperature changes, light, and darkness for 300 hours, which produced a total irradiance level equivalent to 150 kJ/m^2. Accelerated artificial aging was achieved in all the groups using a controlled-irradiance xenon arc filtered through borate borosilicate glass at 0.55 W/m^2. The test cycle involved a black panel temperature [70°C (light) and 38°C (dark)], an approximate humidity [50% (light) and 95% (dark)], and a dry bulb temperature [47°C (light) and 38°C (dark)]. The test cycle comprised 40 min light only, 20 min (light + water spray), 60 min light only, and 60 min (dark+ back water spray). The parameters of the aging procedure used in this research were similar to those applied in former studies[18,19] and equivalent to 1 year of clinical service.

After completion of the aging process, all specimens were exposed to axial compressive loading at a crosshead speed of 0.5 mm/min in a universal testing device (TSTM 02500, Elista Ltd, Istanbul, Turkey). A metal sphere (diameter 4.8 mm) was positioned on the center of the occlusal surface and loaded until fracture. The fracture strength data was recorded in Newtons (N) (Figure 1).

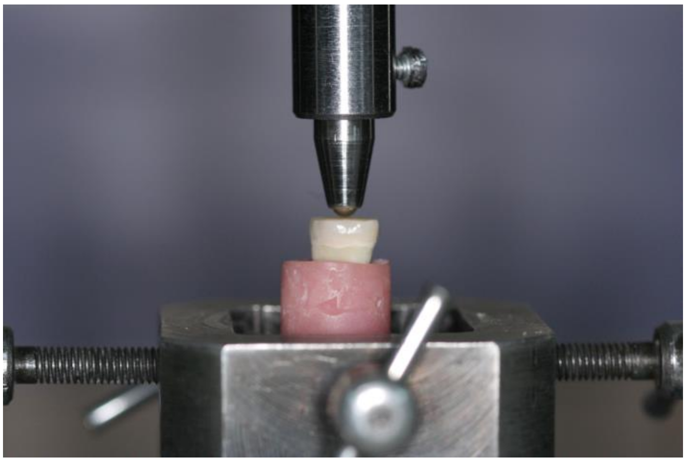

Figure 1.

The compressive test during axial loading

After the fracture test, the type of fracture in each sample was categorized according to Beltrao et al[20] under a stereomicroscope (SZ40, Olympus, Tokyo, Japan) as follows: repairable and irreparable. If the fracture line involved only the restoration or all or part of the cusps, the fracture classified as repairable. If the fracture line divided the tooth into two parts at the floor level of the pulp chamber, the fracture classified as irreparable.[21] The statistical analysis was conducted using SPSS version 22 software (IBM Corp. Armonk, NY, USA). The normality of the data was checked by the Kolmogorov-Smirnov test. As there was normality, the data were evaluated using one-way analysis of variance and Tukey's honestly significant difference test (α=0.05).

RESULTS

The means and standard deviations of fracture strength values in the test groups are presented in Table 2. There was no significant difference among the groups according to One-Way ANOVA (df=2, F= 1.255, P=0.304). The highest mean fracture strength was found in control group (1555.3 N), followed by groups Lava Ultimate (1525 N), IPS Empress CAD (1364.3 N) and CEREC (1231.9 N) respectively.

The type of fracture in each group is shown in Table 3. Lava Ultimate and control groups showed the same fracture rates as 60% repairable and 40% irreparable. Both of the IPS Empress CAD and CEREC groups also showed the same fracture rates: 50% repairable and 50% irreparable. Representative images of the reparable and irreparable fractures were shown in Figure 2.

Table 2.

Mean fracture resistance (N) with standard deviation values in all test groups

Group	N	Mean	Standard Deviation	Minimum	Maximum	95% CI Lower Bound	95% CI Upper Bound
Control	10	1555.3[a]	412.2	805.5	2134	1260.5	1850.1
CEREC	10	1231.9[a]	312.9	786.7	1723.5	1008.1	1455.7
IPS Empress CAD	10	1364.3[a]	545.6	579	2114.3	974	1754.6
Lava Ultimate	10	1525[a]	394	948.5	2133.3	1243.2	1806.8

Same superscript letters indicates that there was no significant difference among the groups (P>.05).

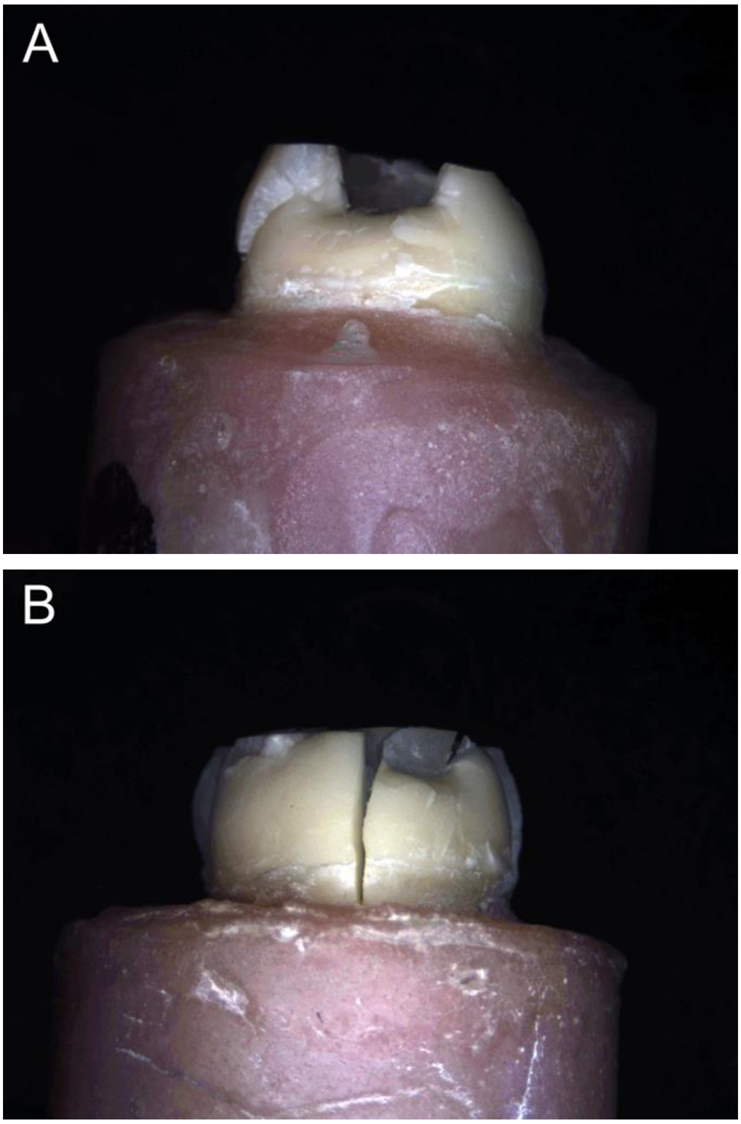

Figure 2.

Representative image of the fracture types:
A) Repairable fracture
B) Irreparable fracture

Table 3.

Fracture modes in the test groups

Fracture Modes	Reparable	Irreparable	Total
Control	6	4	10
CEREC	5	5	10
IPS Empress CAD	5	5	10
Lava Ultimate	6	4	10

DISCUSSION

This study investigated the fracture strength of class I inlays fabricated using three type of machinable material (feldspathic ceramic, leucite-reinforced glass ceramic, and resin nano-ceramic) after artificial aging. Statistical analysis results revealed that no significant difference in fracture strength among the teeth restored with inlays made of different materials and that of intact teeth. Therefore, the null hypothesis of this study could not be rejected.

Clinical studies on restorative materials are essential but are not always possible due to difficulties related to patient follow-up, ethical considerations, and cost. Laboratory tests help to obtain information about restorative materials over a short time period. Using a spherical headpiece on the middle of an occlusal surface with a punctual compression force is the most suitable method for producing fracture patterns similar to those encountered in clinical practice[22], and this method was used to obtain fracture strength values in the present study.

It is almost impossible to imitate the oral conditions of the patients completely, which prevents evaluation of the durability and compatibility of the restorative materials.[23] For this reason, laboratory aging methods have been developed for standardization that allows the comparison of studies by different authors. Under the influence of repeated exposure to ultraviolet light and condensation of distilled water, accelerated artificial aging simulates the chemical and physical environment of the mouth, causing the material to deteriorate in a relatively short period of its clinical life.[24-26] All the groups were attributed to 300 hours of the accelerated artificial ultraviolet aging in this study. The heat and humidity conditions and parameters used in this study corresponded to 1 year of clinical service, as reported in previous studies.[18, 19]

The inlay restored teeth showed similar fracture resistance to intact teeth in this study. This situation has been reported similarly in some studies. Andrade et al[21] investigated the fracture resistance of occlusal veneers of Lava Ultimate, Vita Enamic and IPS e.max CAD (thicknesses of 0.6 mm and 1.5 mm) and reported fracture resistances similar to those of sound teeth. Habekos et al[27] also found no significant difference in the fracture resistance values between the ceramic and composite inlay restorations; however, they reported that the none of the restored teeth achieved the fracture resistance of the intact teeth, unlike this study. Wafaie et al[28] reported that the laboratory composites and pressable glass ceramic inlays showed lower fracture strength than those of the sound teeth.

According to the manufacturers, the elastic modulus of CEREC blocks, the IPS Empress CAD, and the Lava Ultimate are 45 GPa, 62 GPa, and 12.77 GPa, respectively. Xu et al[29] reported that elastic modulus of dentin is 18–22 GPa. In this study, although there was no statistically significant diversity in fracture strength values among the tested groups, resin nano-ceramic inlay group showed fracture strength similar to that of intact teeth and higher fracture strength than the other ceramic materials. The reason for that might be the elastic modulus of resin nano-ceramic material is close to that of dentin.[30]

Some studies have reported that ceramic materials, as well as composite materials, can be used for inlay restorations.[31,32] Liu et al[5] demonstrated that resin composite inlays produced using CAD/CAM had better fracture strength than ceramic inlays created by the same method.

According to Chen et al[33] from the material science perspective, the resin nano-ceramic material is still belonging to the resin composite category. Unlike the ceramics that used in this study, the resin nano-ceramic material contains an organic matrix. It might be expected that the resin nano-ceramic inlays could exhibit significantly higher fracture resistance than the ceramic inlays due to its lower elastic modulus. However; aging is another factor that interferes with mechanical strength; the passage of time leads to the late conversion of monomers into polymers and might cause the degradation of the organic matrix[34] of the Lava Ultimate inlays, and this might explain the indifference between the groups.

According to a retrospective study; chair-side CEREC AC conservative ceramic restorations found clinically successful with a mean survival rate of 95.5% after five years. No significant difference reported between the survival rate of restorations made by CEREC Blocs and IPS Empress CAD blocks.[35] The results of this current study confirm that retrospective study because in-vitro fracture resistance of CEREC Blocks and IPS Empress CAD inlays were similar and statistically no significant difference found between them.

In this study, a considerable variation was observed in the fracture strength of inlay-restored teeth. It is in harmony with the brittle fracture system that might contain internal defects. Also, it is not always possible to control the size and distribution of the internal flaws of each tooth even the restorative materials.[28]

Half of the teeth showed reparable, and half of the teeth showed irreparable (catastrophic) fracture types both of the ceramic groups (Figure 2). Also, 40% of the resin nano-ceramic group showed catastrophic fractures. Guess et al[36] found that premolars restored with standard prepared ceramic onlays were generally showed catastrophic fractures involving tooth structure. Similarly, Yoon et al[37] reported that the different inlay and onlay restored teeth with varying designs of cavity showed predominantly catastrophic failures. Ceramic restoration might accumulate the stresses to the tooth due to their higher elastic modulus compared to dentin until a catastrophic failure occurs (Figure 3).

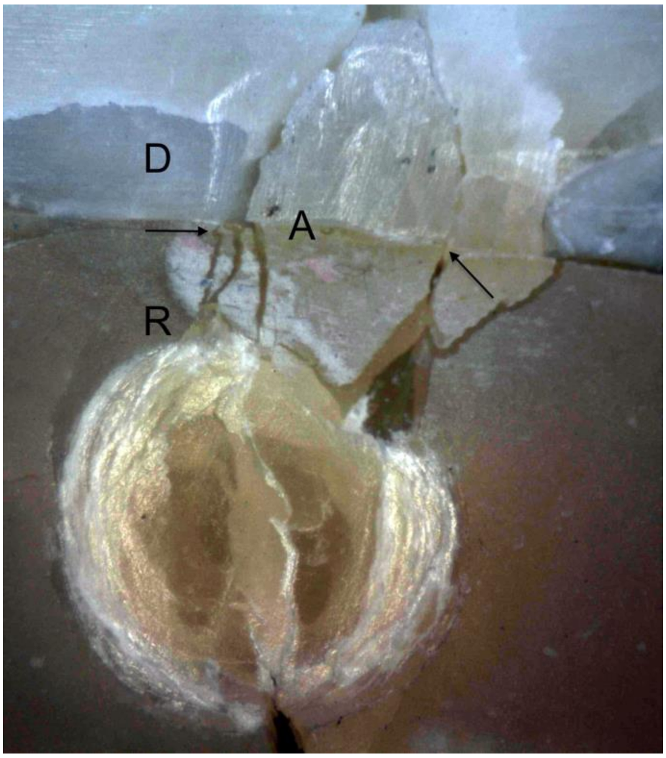

Figure 3.

Arrows indicate the cracks that were moving into the dentine from the restoration. **D:** Dentin; **R:** Inlay restoration; **A:** Adhesive resin cement

Soares at al[38] revealed that "The resin luting agent under a ceramic restoration may act as a soft layer and will reduce the effects of stress concentration." UV aging might hinder the cushioning effect of the adhesive resin cement and lead to catastrophic failures of the restorations. Additionally, artificial aging might reduce the fracture strength by weakening the adhesive bond between the tooth and the restoration.[27] Furthermore, this may again be explained by the elastic modulus of the materials used. The materials with a high elastic modulus (leucite-based and feldspathic ceramics) showed higher irreparable failures as compared with material that had a low elastic modulus (resin nano-ceramic). However, all of the materials fractured above the physiological mastication forces reported in the literature.[39] Therefore, these restorations are likely to be able to withstand high forces in the mouth due to their high fracture strength values, and fractures are unlikely to occur in the mouth for this reason.

The findings of this study suggest that each type of material (leucite-based, feldspathic ceramic, resin nano-ceramic) can be used for Class I inlay restorations. Although no significant difference in fracture strength values was found among the groups, in clinical practice resin nano-ceramic material is possibly more preferable in posterior class I inlay restorations because it has an elastic modulus similar to that of dentin.

The limitations of this study include the lack of a periodontal ligament and one-directional axial loading.[3, 32] The compressive load was applied to the teeth progressively until the fracture occurred in this study. However, dental materials usually fail due to being exposed to chewing cycles, saliva, and stress in the oral environment.[38,40] Therefore, long-term clinical researches are needed to understand the patterns of fatigue in these materials. Besides, only one type of resin cement was used in this study that might affect the fracture resistance of the inlay restorations. The effects of different preparation methods and type of cement on microleakage and fracture strength of inlay restorations should be investigated in further studies.

CONCLUSION

This in vitro study revealed that fracture strength of inlay restorations exceeds that of human masticatory forces, which makes them suitable for use in the posterior region. The type of material used does not influence the fracture strength of inlay-restored molar teeth. In addition, all the restoration materials tested showed fracture strength data similar to those of control teeth, hence could regain any fracture resistance lost during cavity preparation.

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