Original Article / Özgün Araştırma

Comparison of Fracture Strength of Modified PEEK, Nanohybrid Ceramic, Monolithic Zirconium Endocrowns Produced with CAD/CAM System

CAD/CAM Sistemi ile Üretilen Modifiye PEEK, Nanohibrit Seramik, Monolitik Zirkonyum Endokronların Kırılma Dayanımlarının Karşılaştırılması

Gülsüm Sena Çiriş[1], Eyyüp Altıntaş[2]

[1]Alanya Oral and Dental Health Center, Department of Prosthodontics, Antalya, Turkey
[2]Fırat University Faculty of Dentistry, Department of Prosthodontics, Elazığ, Turkey

Abstract

Objective: The aim of this study; comparison of fracture strength of monolithic zirconium, nanohybrid ceramic and modified polyetheretherketone (PEEK) endocrowns produced with computer-aided design/computer-aided manufacturing (CAD/CAM) system.

Materials and Methods: Thirty permanent human first molar teeth of identical anatomical size were collected. After root canal treatment and endocrown preparation were applied to the teeth, they were divided into three groups (n=10). PEEK coping, nanohybrid ceramic and monolithic zirconium, endocrowns were produced by digital methods for each group. The infrastructure of the PEEK group was completed with 1 mm composite to be the same size as the other groups. Cement gap was determined as 100 µm. After cementation of the endocrowns, the specimens were placed in a chewing simulator, equivalent to 6 months of clinical use. For the fracture strength test, the specimens placed on the universal test device were loaded with a head speed of 1 mm/minute until they broke and the specimens were examined under a stereomicroscope to determine the failure type. Statistical analysis of test data was performed.

Results: The highest mean fracture strength of the monolithic zirconium endocrown group (2496.5±189.12 N), secondly, modified peek endocrown group (1728.2±139.26 N) and nanohybrid ceramic endocrown group (1248.8±107.6 N) were determined as the lowest. A statistically significant difference was found between the groups in terms of fracture strength ($p<0.05$).

Conclusion: Modified peek, nanohybrid ceramic, monolithic zirconium endocrowns can be an effective option for the restoration of root canal treated molar teeth with excessive material loss.

Keywords
CAD/CAM, endocrown, fracture strength

Anahtar Kelimeler
CAD/CAM, endokron, kırılma dayanımı

Received/Geliş Tarihi : 10.05.2022
Accepted/Kabul Tarihi : 19.08.2022

doi:10.4274/meandros.galenos.2022.23500

Address for Correspondence/Yazışma Adresi:
Lect. Eyyüp Altıntaş, MD,
Fırat University Faculty of Dentistry,
Department of Prosthodontics, Elazığ, Turkey
Phone : +90 505 478 79 36
E-mail : ealtintas@firat.edu.tr
ORCID ID: orcid.org/0000-0002-7767-9694

Öz

Amaç: Bu çalışmanın amacı bilgisayar destekli tasarım/bilgisayar destekli üretim (CAD/CAM) sistemi ile üretilen monolitik zirkonyum, nanohibrit seramik ve modifiye polietereterketon (PEEK) endokronların kırılma dayanımlarının karşılaştırılmasıdır.

Gereç ve Yöntemler: Anatomik boyutları özdeş olan 30 adet daimi 1. molar insan dişi toplandı. Dişlere kanal tedavisi ve endokron preparasyonu uygulandıktan sonra üç gruba (n=10) ayrıldı. PEEK coping, nanohibrid seramik ve monolitik zirkonyum ve endokronlar her grup için dijital yöntemlerle üretildi. PEEK grubunun alt yapısı diğer gruplarla aynı boyutta olacak şekilde 1 mm kompozitle tamamlandı. Siman aralığı 100 µm olarak belirlendi. Endokronların simantasyonu sonrasında örnekler 6 ay klinik kullanıma eş değer olacak şekilde çiğneme simülatörüne yerleştirildi. Kırılma dayanımı testi için universal test cihazına yerleştirilen örneklere kırılıncaya dek 1 mm/dakika kafa hızıyla yükleme gerçekleştirildi ve numuneler, başarısızlık tipini belirlemek için bir ışık mikroskobu altında incelendi. Test verilerinin istatistiksel analizi yapıldı.

Bulgular: En yüksek kırılma dayanımı ortalaması monolitik zirkonyum endokron grubunun (2496,5±189,1 N), ikinci olarak modifiye peek endokron grubunun (1728.2±139.2 N) ve en düşük olarak nanohibrit seramik endokron grubunun (1248.8±107,6 N) belirlenmiştir. Gruplar arasında kırılma dayanımı açısından istatistiksel olarak anlamlı derecede farklılık bulunmuştur ($p<0,05$).

Sonuç: Modifiye PEEK, nanohibrit seramik, monolitik zirkonyum endokronlar aşırı madde kaybı olan kanal tedavili molar dişlerin restorasyonu için etkili bir seçenek olabilir.

Introduction

The structure of the endodontically treated tooth is weakened as a result of previous caries, fractures and treatment attempts. In addition, endodontic treatment causes the removal of intracoronal and intraradicular tooth structures. As a result of all these endodontic interventions, the fragility of the tooth increases (1). Traditionally, the restoration of endodontically treated teeth is provided by full-crown restorations applied on the intracanal post-core. However, the biomechanical properties of residual dental tissues change during conventional treatment. Complications such as perforation and fracture in the root during post treatment have led to the search for alternative methods (2).

As a result of a 10-year clinical study on endocrown restorations, they stated that the success rate of endocrown restorations is high in teeth with excessive substance loss and in individuals with parafunctional habits. Clinicians have reported that endocrown restorations can be applied as an alternative to traditional fiber-post restorations (3). Endocrown restorations should be especially preferred in cases with different morphology or in angled and calcified canals, in teeth with insufficient clinical crown length, narrow interocclusal distance, large loss of material, and in cases where there is not enough ferrule (4).

The first definition of endocrown was made by Bindl and Mörmann (5) in 1999. These researchers defined endocrown as adhesive restorations consisting of a central retention cavity covering the pulp chamber with a circumferential 90° butt margin, applied to root canal treated teeth with excessive substance loss. The endocrown preparation consists of a 1.0-1.2 mm peripheral butt margin and a central retention cavity extending into the pulp chamber. Endocrown restorations are monoblock structures with core and crown that do not receive support from the root canal cavity (5). The butt margin design allows the prevention of microleakage at the restoration-tooth interface, the prevention of shear stresses, and the preservation of the peripheral enamel layer around the margin (6).

Materials and Methods

This study was carried out in Fırat University Faculty of Dentistry, Department of Prosthetic Dentistry, with the 06.02.2020 decision dated and 2020/03-06 numbered, taken from the Fırat University Non-Interventional Research Ethics Committee. In the study, 30 mandibular first molar teeth with 7-8 mm cervico-occlusal distance and 13-15 mm root length, extracted for periodontal or orthodontic reasons, were used. Detertrage and ultrasonic cleaning processes were applied to remove tissue residues or dental calculus on the teeth. The coronal parts of the teeth were removed under water cooling with a steel separator 2 mm above the cemento-enamel junction. Then, root canal treatment was applied to all of the sample teeth in accordance with the standards.

After the root canal treatment procedures were completed, the root canal paste residues were cleaned. After the root canal entrances and canal mouth dentin were etched with acid, the 5th generation adhesive system Any-Bond (MD Clus, South Korea) was applied and left to act for 20 seconds. It was dried for 5 seconds with low air pressure and polymerized for 10 seconds with a light-emitting diode (LED) light device (Coxo, Guangdong, China). Then nanohybrid flowable composite (Grandio Flow, Cuxhaven, Germany) was applied to the canal entrances and pulp chamber and cured with LED light for 20 seconds. The teeth were embedded in acrylic resins (Imicryl; Konya, Turkey) poured into polyvinyl chloride pipes with a diameter of 3 cm and a height of 5 cm, with the long axis of the roots perpendicular to the ground and 2 mm below the enamel-cementum composition (representing the bone level). The teeth were kept in distilled water for 1 week to harden the endodontic canal sealer.

Standard endocrown preparations were performed by a single operator. In order to ensure standardization, the cavity depth was measured with the aid of a periodontal probe and determined as 4 mm. The pulp chamber floor was prepared flat. Cavity inner edge angles were finished as a butt margin with an angle of 90°. The preparation was carried out with a cavity wall thickness of 2 mm (Figure 1).

Digital impressions of the samples were taken in the laboratory with an extraoral scanner (Dwos 3 Series, Dental Wings Inc, Montreal, Canada). The surface of the samples was coated with titanium dioxide powder [Dr. Mat Dental computer-aided design/computer-aided manufacturing (CAD/CAM) White Scan Spray, İstanbul, Turkey] to eliminate light reflections that may occur during impression taking. Polyetheretherketone (Peek) endocrowns were designed with 6 mm to be veneered with 1 mm composite later, endocrowns in the other group 7 mm cervico-occlusal height with the CAD program (DWOS software, Dental Wings Inc, Montreal, Canada). Cement gap was determined as 100 µm. The inner surfaces of the samples, which were adapted to the teeth after being produced in a milling device (K5; vhf camfacture AG, Germany), were roughened with Al_2O_3 powder in a sandblasting device (Rotaks, İstanbul, Turkey) before cementation.

After the production of monolithic zirconium endocrowns was completed from blocks (KATANA

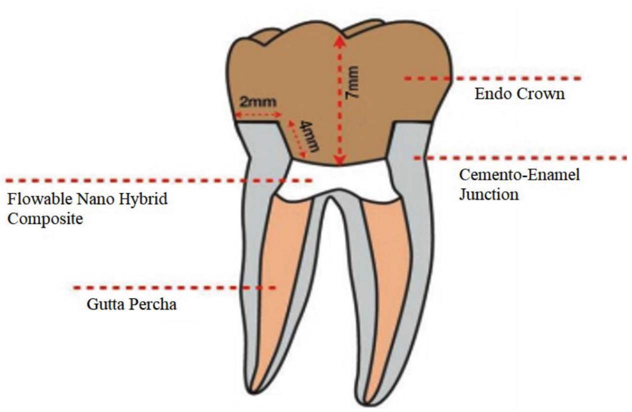

Figure 1. Endocrown preparation design

UTML Zirconia, Kuraray Noritake INC., Okayama, Japan), they were sintered in a sintering furnace (Protherm Furnaces, İstanbul, Turkey) for 1.5 hours at 1,550 °C. Endocrowns fabricated using nanohybrid ceramic blocks (Cerasmart, GC Corp., Tokyo, Japan) were finished with silicone discs and polishing paste (Diapolisher GC Corp., Tokyo, Japan) according to the manufacturer's instructions. Visio.Link (Bredent, Germany) was applied to the upper surface of the substructures produced from PEEK block (JUVORA, Juvora Ltd. Thornton Cleveleys, Lancastershire, England) with a small brush and cured for 120 seconds in the polymerization device (Labolight DUO, GC, Europe). Thanks to the transparency of SX plates, manipulation and polymerization can be facilitated, and thus homogeneous and smooth composite veneering process can be performed with the same size as other samples. Indirect composite resin (Crea.lign, Bredent, Germany) was applied to the adhesive-applied PEEK substructure surface using the previously prepared SX plaque index and 30 seconds prepolymerization was carried out. Final polymerization was carried out in the device for 4.5 minutes.

In order to ensure standardization, 50 N force was applied to the restorations for 60 seconds with a dynamometer (Algol, Japan), and the overflow resin cements (Panavia F 2.0, Kuraray Noritake INC. Okayama, Japan) were removed. Then, polymerization was performed on each surface for 20 seconds by means of a LED light device, and cementation was completed. Endocrown restorations belonging to 3 different groups were loaded into the dual axis chewing simulator (Esetron Smart Robotechnologies, Mod Dental, Ankara, Turkey) (Table 1). In the chewing simulator, 120,000 cycles were applied to the samples, corresponding to 6 months of clinical use. After the aging process, the specimens were tested for fracture strength by means of a universal test device (Instron device 3345, Norwood, MA, USA). A spherical steel tip with a diameter of five millimeters is positioned on the occlusal surface (central fossa) of the restorations. The force (N) values applied until the samples were broken along the long axis of the tooth with a head speed of 1 mm/min were recorded. The failure mode of each specimen was evaluated by observation under the stereomicroscope, 10X magnification (Leica MZ 12; Leica Microsystems GmbH, Wetzlar, Germany).

Table 1. Study groups and sample numbers		
Groups	**n**	**Contents**
Group 1	10	Endocrowns produced by CAD/CAM from monolithic zirconium blocks
Group 2	10	Endocrowns fabricated by CAD/CAM from nanohybrid ceramic blocks
Group 3	10	Modified PEEK endocrowns obtained by veneering of the substructures produced with CAD/CAM from PEEK blocks with composite
TOTAL	30	
CAD/CAM: Computer-aided design/computer-aided manufacturing, PEEK: Polyetheretherketone		

Burke classification was used while performing the fracture type analysis (7):

Type 1: Fracture occurring only in endocrown restoration.

Type 2: Fracture involving a small tooth fragment with endocrown restoration.

Type 3: Fracture involving more than half of the tooth with endocrown restoration (above the enamel-cementum border).

Type 4: Fractures below the cemento-enamel junction.

Statistical Analysis

IBM SPSS Statistics 22 program was used for statistical analysis. Parameters were suitable for normal distribution that determined by Kolmogorov-Smirnov and Shapiro-Wilks tests. The One-Way ANOVA test was used to compare the parameters between groups, and the Tukey HSD test was used to determine the group that caused the difference. Significance was evaluated at the $p<0.05$ level.

Results

The fracture strength results of the groups used in the study are summarized in Table 2. The average fracture strength of the monolithic zirconium endocrown group (2496.5±189.12 N) was statistically significantly higher than the modified PEEK endocrown (1728.2±139.26 N) and nanohybrid ceramic endocrown groups (1248.8±107.61 N) ($p1<0.001$; $p2:0.001$). The average fracture strength of the modified PEEK endocrown group was statistically significantly higher than the nanohybrid ceramic endocrown group ($p<0.001$) (Figure 2). No breakage was observed in any of the samples after the chewing simulator. Type 1 fracture (100%) in the entire modified PEEK endocrown group, type 1 fracture (70%) and type 2 fracture (30%) in the nanohybrid ceramic endocrown group, type 2 (10%), type 3 (40%) and type 4 (50%) fracture in the monolithic zirconium endocrown group were observed (Table 3).

Discussion

It is aimed that dental restorations are stable against the forces occurring during function, and it has

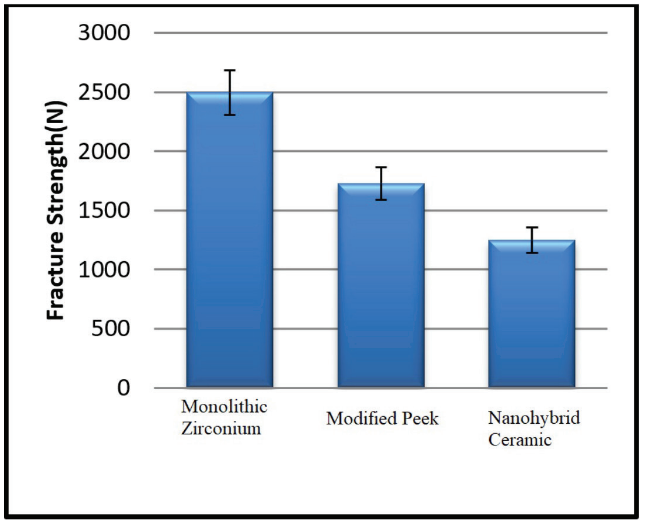

Figure 2. Average fracture strength graph of the groups

Table 2. Fracture strength values and statistical analysis results for the study groups		
Fracture strength (N)		
	Minimum-Maximum	**Mean ± SD**
Monolithic zirconium	2,152-2,792	2496.5±189.12
Modified PEEK	1,513-1,938	1728.2±139.26
Nanohybrid ceramic	1,073-1,437	1248.8±107.61
SD: Standard deviation		

Table 3. Percentage values of fracture types of endocrown groups				
	Type 1	**Type 2**	**Type 3**	**Type 4**
Modified PEEK	100%	0%	0%	0%
Nanohybrid ceramic	70%	30%	0%	0%
Monolithic zirconium	0%	10%	40%	50%
PEEK: Polyetheretherketone				

been reported in studies that the maximum bite force in the posterior region varies between 200-880 N (8). Kiliaridis et al. (9) that there is variation in maximum bite force between the sexes; reported this value as 807 N for men and 650 N for women. The fracture strengths of the CAD/CAM endocrown systems tested in our in vitro study were found to be well above the average of the maximum chewing forces.

In the clinical study of Tammam (10), it was reported that the endocrowns had a high durability rate (94.87%) as a result of 3-year follow-up of modified PEEK, monolithic zirconium and lithium disilicate endocrowns. In our study, in which we used monolithic zirconium and modified PEEK groups similarly, 120,000 cycles were applied in the simulator, equivalent to 6 months of clinical use, and no breakage was observed in any of the samples.

Rojpaibool and Leevailoj (11) investigated the effects of different resin cements on the fracture strength of lithium disilicate ceramics in the range of 100 µm and 300 µm cement gap. They reported that ceramics with 100 µm cement gap showed higher fracture strength in both resin cements. In our study, the cement gap of the endocrowns produced with CAD/CAM technology was designed to be 100 µm.

Elashmawy et al. (12), compared the fracture strength of monolithic zirconium, Vita Enamic, and veneered PEEK endocrowns. The highest fracture strength was found in monolithic zirconium endocrowns (1810.20±119.56 N) and the lowest value was found in veneered PEEK endocrowns (502.60±11.53 N). This difference was found to be statistically significant, similarly, in our study.

In their study, Al-Shibri and Elguindy (13) determined the fracture strength of Cerasmart endocrowns to be 1522.64±352.52 N, and Kassis et al. (14) 1300.53 N, Taha et al. (15) reported it as 1508.5± 421.7 N. In our study, the fracture strength of Cerasmart endocrowns was found close to these values (1248.8±107.61 N).

Beleidy and Ziada (16) compared the fracture strength of crown restorations produced from PEEK material using different veneering techniques. The fracture strength of PEEK crowns veneered with Crea. lign composite was found to be 1674 ±224.48 N. These values are similar to our study.

Shams et al. (17) investigated the endocrowns fracture strength of modified PEKK formed by veneering with IPS e.max CAD and IPS e.max CAD applied to extracted premolar teeth. In the study, the fracture strength value of the modified PEKK endocrowns was 1831.37±240.69 N, and it was found to be statistically significantly higher than the IPS e.max CAD endocrown. The fracture strength of the modified PEEK endocrowns in our study was 1728.2±139.26 N, which is close to Shams et al. (17) study.

Tartuk et al. (18) compared the fracture strength of monolithic zirconium, hybrid ceramic, PEEK crowns in their study. The fracture strength value of the monolithic zirconium group (3292±192 N) was found to be significantly higher than PEEK (2214±236 N) and hybrid ceramic (2325±264 N). However, no significant difference was found between PEEK and hybrid ceramics. In our study; a significant difference was detected between all groups. The difference between our study and Tartuk et al.'s (18) may be due to their working on crown restorations, using of PEEK without veneering in their study and preferring different block brands.

Elashmawy et al. (12) also evaluated the types of fracture in their study. Restorable fractures occurred in all veneered PEEK endocrowns. Irreversible fractures occurred in 80% of monolithic zirconium endocrowns. Similar results were obtained with our study in terms of failure types.

The elastic modulus of the materials used in our study is different from each other [dentin: 14.7 GPa, zirconium: 200 GPa, peek: 3-4 GPa (19), nanohybrid ceramic 12.16 GPa (20)]. If a material which has a higher elastic modulus compared to dentin is chosen, the restoration may become more rigid than the tooth structure. However, if a material close to the elastic modulus of dentin is chosen for the restoration, the restoration exhibits biomechanical behavior similar to tooth structure. As a result, the material used in the production of the endocrown affects the performance of the restoration (21). Although the modulus of elasticity values of nanohybrid ceramic and peek materials are close, the difference in the fracture strength test results in our study may be due to the use of peek structure with composite veneered (non-monolithic). The reason for the fracture type involving the tooth tissue in the monolithic zirconium group is also due to the fact that the elastic modulus of the material is higher than the surrounding dentin tissue and it creates stress in this region.

Ghajghouj and Taşar-Faruk (22) noticed in their study that PEEK endocrown restorations provide reducing of the crack formation of tooth due to its low elastic modulus close to dentin tissue. They reported that peek is a material with sufficient fracture resistance for endocrown production. The results of our study also support this view.

Conclusion

Although monolithic zirconium endocrown restorations show high durability, they should not be preferred in patients with excessive chewing forces such as bruxism, due to their high modulus of elasticity compared to dentin.

Nanohybrid ceramic endocrowns can be used clinically safely due to their modulus of elasticity close to dentin. However, they have superior aesthetic properties.

In our study it was observed that the fracture strength values of endocrown groups produced with CAD/CAM technology were much higher than the average of the intraoral chewing forces. This shows that all of the endocrown groups in our study can resist intra-oral forces.

Ethics

Ethics Committee Approval: This study was carried out in Fırat University Faculty of Dentistry, Department of Prosthetic Dentistry, with the 06.02.2020 decision dated and 2020/03-06 numbered, taken from the Fırat University Non-Interventional Research Ethics Committee.

Informed Consent: Informed consent is not required.

Peer-review: Externally peer-reviewed.

Authorship Contributions

Surgical and Medical Practices: G.S.Ç., Concept: E.A., Design: G.S.Ç., Data Collection or Processing: G.S.Ç., Analysis or Interpretation: E.A., Literature Search: G.S.Ç., Writing: E.A.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study received no financial support.

References

1. Cohen S BR, Walton R, Torabenijad M. Pathways of the Pulp. St Louis: Mosby; 1998.
2. Assif D, Gorfil C. Biomechanical considerations in restoring endodontically treated teeth. J Prosthet Dent 1994; 71: 565-7.
3. Belleflamme MM, Geerts SO, Louwette MM, Grenade CF, Vanheusden AJ, Mainjot AK. No post-no core approach to restore severely damaged posterior teeth: An up to 10-year retrospective study of documented endocrown cases. J Dent 2017; 63: 1-7.
4. El-Damanhoury HM, Haj-Ali RN, Platt JA. Fracture resistance and microleakage of endocrowns utilizing three CAD-CAM blocks. Oper Dent 2015; 40: 201-10.
5. Bindl A, Mörmann WH. Clinical evaluation of adhesively placed Cerec endo-crowns after 2 years-preliminary results. J Adhes Dent 1999; 1: 255-65.
6. Rocca GT, Krejci I. Crown and post-free adhesive restorations for endodontically treated posterior teeth: from direct composite to endocrowns. Eur J Esthet Dent 2013; 8: 156-79.
7. Burke F. The effect of variations in bonding procedure on fracture resistance of dentin-bonded all-ceramic crowns. Quintessence Int 1995; 26: 293-300.
8. Claus H. The structure and microstructure of dental porcelain in relationship to the firing conditions. Int J Prosthodont 1989; 2: 376-84.
9. Kiliaridis S, Kjellberg H, Wenneberg B, Engström C. The relationship between maximal bite force, bite force endurance, and facial morphology during growth: A cross-sectional study. Acta Odontol Scand 1993; 51: 323-31.
10. Tammam R. Clinical evaluation of monolithic Zirconia (5Y), Lithium Disilicate and modified PEEK CAD-CAM endocrown materials, 3-year clinical prospective study. EDJ 2021; 67: 635-50.
11. Rojpaibool T, Leevailoj C. Fracture resistance of lithium disilicate ceramics bonded to enamel or dentin using different resin cement types and film thicknesses. J Prosthodont 2017; 26: 141-9.
12. Elashmawy Y, Elshahawy W, Seddik M, Aboushelib M. Influence of fatigue loading on fracture resistance of endodontically treated teeth restored with endocrowns. J Prosthodont Res 2021; 65: 78-85.
13. Al-Shibri S, Elguindy J. Fracture resistance of endodontically treated teeth restored with lithium disilicate crowns retained with fiber posts compared to lithium disilicate and cerasmart endocrowns: in vitro study. Dentistry 2017; 7: 464.
14. Kassis C, Khoury P, Mehanna CZ, Baba NZ, Bou Chebel F, Daou M, et al. Effect of inlays, onlays and endocrown cavity design preparation on fracture resistance and fracture mode of endodontically treated teeth: An in vitro study. J Prosthodont 2021; 30: 625-31.
15. Taha D, Spintzyk S, Sabet A, Wahsh M, Salah T. Assessment of marginal adaptation and fracture resistance of endocrown restorations utilizing different machinable blocks subjected to thermomechanical aging. J Esthet Restor Dent 2018; 30: 319-28.

16. Beleidy M, Ziada A. Marginal Accuracy and Fracture Resistance of Posterior Crowns Fabricated from CAD/CAM PEEK Cores Veneered with HIPC or Nanohybrid Conventional Composite. EDJ 2020; 66: 2541-52.
17. Shams A, Sakrana AA, Abo El-Farag SA, Özcan M. Assessment of Biomechanical Behavior of Endodontically Treated Premolar Teeth Restored with Novel Endocrown System. Eur J Prosthodont Restor Dent 2022; 30: 20-35.
18. Tartuk BK, Ayna E, Başaran EG. Comparison of the load-bearing capacities of monolithic PEEK, zirconia and hybrid ceramic molar crowns. Meandros Med Dent J 2019; 20: 45-50.
19. Tekin S, Cangül S, Adıgüzel Ö, Değer Y. Areas for use of PEEK material in dentistry. Int Dent Res 2018; 8: 84-92.
20. Cerasmart for PlanMill Brochure, 2016. Available from: https://www.gcamerica.com/products/digital/CERASMART_Planmill/GCA_CERASMART_PlanMill_Bro-iPad.pdf
21. Sedrez-Porto JA, Rosa WL, da Silva AF, Münchow EA, Pereira-Cenci T. Endocrown restorations: A systematic review and meta-analysis. J Dent 2016; 52: 8-14.
22. Ghajghouj O, Taşar-Faruk S. Evaluation of fracture resistance and microleakage of endocrowns with different intracoronal depths and restorative materials luted with various resin cements. Materials (Basel) 2019; 12: 2528.