ORİJİNAL ARAŞTIRMA ORIGINAL RESEARCH

DOI: 10.5336/dentalsci.2021-84878

Comparative Evaluation of Fracture Strength and Failure Mode of Three Different CEREC Omnicam Endocrowns: An *In Vitro* Study

Üç Farklı CEREC Omnicam Endokronun Kırılma Dayanıklılığı ve Kırılma Modlarının Karşılaştırılması: *İn Vitro* Bir Çalışma

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ABSTRACT Objective: The aim of this in vitro study was to evaluate fracture strength of porcelain endocrown produced by a computer aided design/computer aided manufacturing (CAD/CAM) system using different types of ceramic blocks. **Material and Methods:** Forty-five extracted human mandibular molars were divided randomly into 3 groups (n=15). Standardized endodontic treatment was applied the forty-five molars in 3 groups, received endocrown preparations. Experimental groups were; Group 1 (VS); Lithium silicate reinforced with zirconia (Vita Suprinity, Vita Zahnfabrick, Bad Säckingen, Germany), Group 2 (EM); Lithium silicate (IPS e.max CAD, Ivoclar Vivadent, Schaan, Lichtenstein) and Group 3 (CS); Resin nanoceramic (Cerasmart, GC, Tokyo, Japan). Restorations were cemented with dual-cure resin cement Variolink N (Ivoclar Vivadent, Schaan, Liechtenstein) and samples were stored in distilled water at 37°C for 24 hours. All samples were subjected to thermocycling for 5,000 cycles in water baths between 5°C and 55°C. The fracture strength of samples was determined under compressive loads at a 0.5 mm/min crosshead speed until fracture. The maximum fracture strength (Newton) values of the restorations were recorded. Fracture strength data were evaluated with one-way ANOVA (p=0.05). **Results:** The highest fracture strength values were observed in CS (2,379.6±483.07 N), which was significantly higher than the other groups (p<0.05). No significant difference was found between VS (1,321.2±379.47 N) and EM (1,489.7±240.65 N) (p>0.05). **Conclusion:** Resin nanoceramic endocrowns produced using CEREC Omnicam system demonstrated significantly higher fracture strength values than the other groups.

Keywords: CAD/CAM; endocrown; fracture strength

ÖZET Amaç: Bu in vitro çalışmada, bilgisayar destekli tasarım/bilgisayar destekli üretim [computer aided design/computer aided manufacturing (CAD/CAM)] sisteminde kullanılan içeriği farklı seramik bloklardan hazırlanan porselen endokronların kırılma dayanıklılığı açısından değerlendirilmesi amaçlanmıştır. **Gereç ve Yöntemler:** Kırk beş adet çekilmiş insan alt molar dişi rastgele 3 gruba ayrıldı (n=15). Üç gruptaki 45 dişe standart kanal tedavisi işlemi uygulanıp, endokron preparasyonu yapıldı. Deney grupları şu şekilde belirlendi: Grup 1; Zirkonyum ile güçlendirilmiş lityum silikat seramik (Vita Suprinity, Vita Zahnfabrick, Bad Säckingen, Almanya), Grup 2; Lityum disilikat seramik (IPS e.max CAD, Ivoclar Vivadent, Schaan, Lichtenstein) ve Grup 3; Rezin hibrit nanoseramik (Cerasmart, GC, Tokyo, Japonya). Restorasyonlar, "dual-cure" rezin siman Variolink N (Ivoclar Vivadent, Schaan, Lihtenştayn) kullanılarak dişlere simante edildi ve örnekler distile suda 37°C'de 24 saat süre ile bekletildi. Daha sonra tüm örnekler 5°C ve 55°C arasında 5.000 döngülük termal siklus işlemine tabi tutuldu. Örneklere üniversal bir test cihazında kırılma dayanıklılığı testi 0,5 mm/dk hızla yükleme yapılarak uygulandı. Restorasyonların maksimum kırılma dayanıklılığı (Newton) değerleri kaydedildi. Örneklerin kırılma tipleri incelendi. Kırılma dayanıklılığı testi bulguları, tek yönlü ANOVA varyans analizi ile değerlendirildi (p=0,05). **Bulgular:** En yüksek ortalama kırılma dayanıklılığı Grup 3'te görüldü (2.379,6±483,07 N). Bu değer diğer grupların ortalama değerlerinden anlamlı olarak yüksek bulundu (p<0,05). Grup 1 (1.321,2±379,47 N) ve Grup 2'nin (1.489,7±240,65 N) ortalama kırılma dayanıklılığı değerleri arasında istatistiksel olarak anlamlı bir fark bulunmadı (p>0,05). **Sonuç:** CEREC Omnicam sistemi ile üretilen rezin nanoseramik endokronların kırılma dayanıklılığının diğer gruplardan anlamlı olarak yüksek olduğu sonucuna varıldı.

Anahtar Kelimeler: CAD/CAM; endokron; kırılma dayanıklılığı

The rehabilitation of dehydrated non-vital teeth with extensive structure loss is a great challenge for clinicians.[1] To protect the weakened tooth structure and maintain structural integrity, treatment options should carefully be considered and material choice becomes even more important for the longevity of these restora-

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Peer review under responsibility of Turkiye Klinikleri Journal of Dental Sciences.

Received: 13 Jun 2021 ***Received in revised form:*** 18 Nov 2021 ***Accepted:*** 21 Dec 2021 ***Available online:*** 24 Dec 2021

tions.[2] In addition, for teeth with poor integrity, failure of the restoration may lead to unrepairable failures and finally extraction of the non-vital tooth.[3]

Simplified inlay restoration preparations provide protection of unnecessary structure loss for endodontically treated teeth with large mesial-occlusal-distal (MOD) restorations. Structural strength of tooth becomes doubtful when preparation design enlarges. As an alternative to conventional crown treatments with extensive preparation necessity, ceramic endocrown restorations reduce the requirement for macroretentive geometry and the esthetic outcome is desirable for patients.

In general, different types of posts are preferred to support the crown and retain a strengthened core. Esthetic expectations of patients causes clinicians to prefer tooth colored fiber reinforced posts.[4] Some studies have shown that elastic fiber posts tend to cause leakage between restorations and luting resin cement which may cause fractures in the restoration.[5,6] Although findings of researches regarding fiber posts showed acceptable results, Bindl and Mörmann suggested a new approach for endodontically treated teeth with severe damage described as crowns with an internal part for pulp cavity chamber.[7-9] Endocrowns can cover all cusps and the internal part in the pulp chamber supports the main crown. Also, the internal part eliminates the steps of fiber post application. This technique is less time consuming and more conservative because no preparation is needed in the root canal for post application.[10] Endocrowns can be preferred at teeth with short, obliterated, dilacerated or fragile roots.[11] An *in vitro* study compared endocrowns and crowns after fiber post application, and the fracture resistance values were similar.[12] However, more unrepairable fractures were observed at endocrown groups. Advances in digital technology led dentists to restore teeth with more esthetic restorations in a short time. The chair-side approach is more acceptable and comfortable for patients.[13] Furthermore, computer assisted design and computer assisted manufacturing (CAD/CAM) systems provide many restorative material options with less steps and application time than crowns with post-core preparations. CEREC systems have been available for many years and developments in digital dentistry has led clinicians to restore larger preparations more easily with better mechanical properties. CEREC Bluecam system needed powder application on the teeth for digital impression, however CEREC Omnicam is a powder-free 3D system which is more convenient. In 1985, CEREC 1 was introduced and since then significant advances in CEREC CAD/CAM systems have eliminated problems in the impression and design sections.[14] So that, the 3D powder-free version CEREC Omnicam system has many advantages than the first versions, such as better impressions in a short period and better anatomical tooth designs. One of the most important problems reported in first-generation CEREC systems was the margin of discrepancies beyond 100 μm, which could affect the survival rates due to secondary caries.

Recently, biocompatible materials such as lithium disilicate ceramic, resin nanoceramic and zirconia-reinforced ceramics are available in the market for CAD/CAM systems. Resin nanoceramic materials have similar elasticity modulus to dentin (12.8 GPa) which provides an advantage for less crack occurrence under forces and have better fracture strength results than other ceramics.[15] Clinical and laboratory studies have exhibited successful results for resin nanoceramic indirect restorations.[16,17] Resin nanoceramics have been developed to obtain elasticity modulus similar to dentine, so that they can absorb occlusal stresses. These qualities may cause them to be preferred for large restorations. In addition, the mechanical properties of resin nanoceramic restorations were shown to be comparable with ceramics.[18] Also, they can be polished easily using rotary instruments and rubber caps. Glazing procedures in the furnace is not needed for resin nanoceramic restorations.

The aim of this study was to compare the fracture strength and failure modes of endocrowns fabricated using three different CAD/CAM blocks. The null hypothesis was that there would be no significant difference among endocrown restorations' fracture strengths fabricated with three different CAD/CAM blocks.

MATERIAL AND METHODS

Compositions of the materials used are presented in Table 1. The study was approved by the Hacettepe University Non-interventional Clinical Research Ethics Committee (Ethic no: GO 15/670-09, date: 04 November 2015). The study followed the Declaration of Helsinki principles. All patients signed a written informed consent form. Forty-five similar-sized sound mandibular molars were selected. A digital caliper (INSIZE CO., LTD. Jiangsu Province, China) was used to determine the bucco-lingual and mesio-distal dimensions (maximum 10% deviation was allowed). The inclusion criteria for the teeth were: (1) intact, (2) no cracks or fractures and (3) absence of previous restorations. The visual inspection was carried out with magnifying glasses (Standard Loupes 3.0x, Keeler, Broomall, USA). Teeth were stored in 0.1% thymol until the beginning of the study, then cleaned with hand instruments and polished with a rubber cup using a low-speed handpiece.

A diamond disc (Isomet, Buehler, Illinois, USA) was used to separate crowns from the roots with water-cooling. Separation line was 2 mm above the cementoenamel junction (CEJ). The pulp chambers were prepared using a fissure carbide bur. Protaper system (ProTaper, Dentsply Maillefer, Ballaigues, Switzerland) was used for root canals treatment using SX, S1, S2, F1 (20/.07) and F2 (25/.08) files, respectively. For distal canals F3 and for the mesial canals F2 were used as a master file. After using each file, 2 mL 2.5% sodium hypochlorite (NaOCl, Endosolve HP, Imicryl, Konya, Turkey) was injected as an irrigant. Endodontic accesses of cavities were sealed with a layer of resin-modified glass ionomer cement after gutta-percha placement and removal of excessive material. To set the sealer, all samples were stored in 100% humidity for 7 days.

All teeth were embedded in acrylic resin (Paladent RR, Heraeus Kulzer, Hanau, Germany) up to 2 mm below the CEJ, with the long axis of the tooth perpendicular to the base of acryl. All teeth received the same preparation design. The resin cement thickness was adjusted leaving a 2 mm coronal preparation shown in Figure 1. Cavity internal walls were given an extending 8-10°divergence using a flame ended diamond bur and the marginal edges had a butt joint preparation design. The finished preparation is presented in Figure 2. Preparation dimensions were checked using a periodontal probe (cavities were oval-shaped with 2-2.4 mm mesial-distal width and 4.5-4.8-mm buccal-palatal width). The gutta percha was sealed using a glass ionomer cement and for standardization all preparations were checked to confirm.

Teeth were randomly assigned into 3 groups (n=15): (1) Vita Suprinity (VS), (2) IPS e.max CAD (EM), (3) GC Cerasmart (CS). Endocrown restorations were produced using CEREC Omnicam system

TABLE 1: Fracture strength values and standard deviations of experimental groups.

Material	Fracture strength (N)±SD
Vita suprinity	1321.2^{b}±379.47
IPS e.max CAD	1489.7^{b}±240.64
Cerasmart	2379.6^{a}±483.06

Same small letter in same column indicates no significant difference (p<0.05).
SD: Standard deviation.

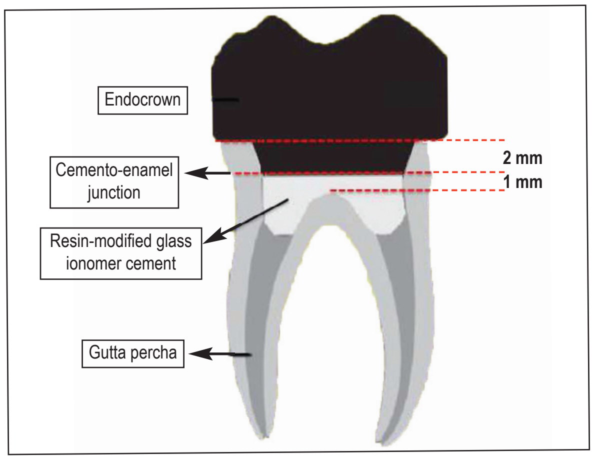

FIGURE 1: Schematic diagram of endocrowns.

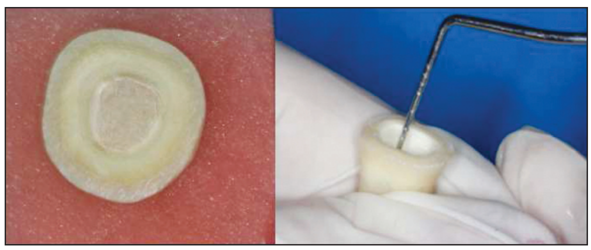

FIGURE 2: Representative cavity preparation design of samples.

(Dentsply Sirona, Bensheim, Germany). CEREC 4.0 Software was used to design the restorations (Figure 3). Milling was conducted with the CEREC MC milling machine. Crystallization was conducted in Progmat P310 (Ivoclar Vivadent, Schaan, Liechtenstein) furnace for VS and EM endocrowns following the manufacturer's instructions. After crystallization, EM and VS restorations were glazed. CS restorations were polished using a paste (Diapolisher paste, GC, Tokyo, Japan) with low-speed handpiece. The preparations were cleaned with pumice for 10 s and rinsed with water for 10 s.

Inner surfaces of VS and EM endocrowns were etched using 9.5% hydrofluoric acid gel (Porcelain etchant, Bisco, Illinois, USA) for 60 s. Then endocrowns were rinsed for 20 s and dried with air-spray. A silane agent (Monobond N, Ivoclar Vivadent, Schaan, Liechtenstein) was applied to the inner surfaces of all restorations for 60 s. The enamel of preparations was etched for 30 s and dentin for 15 s using 37.5% phosphoric acid, rinsed and dried.

A dual-cure resin cement system (Variolink N, Ivoclar Vivadent, Schaan, Liechtenstein) was used according to manufacturer's instructions for cementation of all endocrowns. The resin cement was applied to the inner surfaces of the endocrowns. Afterwards, they were placed on the preparations by finger pressure. Resin cement was cured for 60 s from each side. Polishing discs were used for the removal of excess cement. All specimens were stored in distilled water at 37°C for 24 hours. Afterwards, 5,000 cycles of thermocycling was applied in water baths between 5°C and 55°C (MTE 101, MOD Dental, Esetron, Ankara, Turkey).

A compressive load was applied with a round tip 5 mm in diameter at a cross-head speed of 0.5 mm/min until fracture occurred in a universal testing machine (Lloyd Instruments LR 50K, AMETEK GmbH, Meerbusch, Germany). The maximum load at which the specimens fractured was recorded in Newtons. Fractures were examined for each specimen under a stereomicroscope (Leica MZ 16A, Leica Microsystems, Switzerland) to determine failure modes. The fracture types were categorized in 4 failure modes in Table 2.[15]

STATISTICAL ANALYSES

Data obtained for fracture strength were analyzed statistically using one-way ANOVA and Tukey HSD pairwise comparison test (SPSS version 20.0, SPSS, Chicago, IL, USA). The level of statistical significance was $p<0.05$.

FIGURE 3: Design of endocrown restoration on computer aided design/computer aided manufacturing software.

TABLE 2: Failure modes for restorations.

Type I	Debonding of endocrown
Type II	Fracture of endocrown
Type III	Fracture of the endocrown/tooth complex above the enamel-cement junction, without periodontal involvement
Type IV	Fracture of the endocrown/tooth complex below the enamel-cement junction

Types I, II and III were called as "repairable" failures, whereas fracture in Type IV was termed as "non-repairable" failures.

RESULTS

The results of the fracture strength tests are shown in Table 1. CS group (2379.6±483.06) had the highest fracture strength value, followed by EM group (1489.7±240.64) and VS group (1321.2±379.47). CS group showed a significantly higher fracture strength value than EM and VS ($p<0.05$). However, VS and EM groups exhibited similar fracture strength values ($p>0.05$) (Figure 4).

The failure type ratios of three experimental groups are given in Figure 5. Most of the endocrowns at VS, EM, CS groups demonstrated Type IV failures (respectively 73.3%, 66.6%, 73.3%). Type III failures were seen in three VS, 3 EM and 5 CS endocrowns.

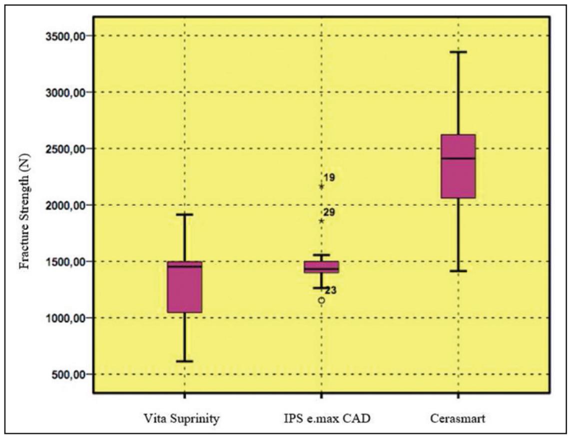

FİGURE 4: Fracture strength values of experimental groups.

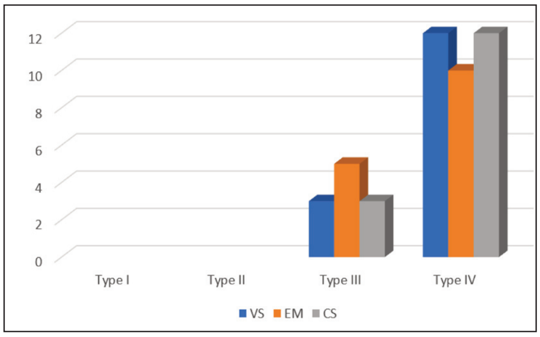

FIGURE 5: Failure types of experimental groups. Vita Suprinity **(VS)**, IPS e.max CAD **(EM)**, GC Cerasmart **(CS)** **Type I:** Debonding of endocrown; **Type II:** Fracture of endocrown; **Type III:** Fracture of the endocrown/tooth complex above the enamel-cement junction, without periodontal involvement; **Type IV:** Fracture of the endocrown/tooth complex below the enamel-cement junction.

DISCUSSION

In the present study, the fracture strength values and fracture modes of endocrowns were assessed on mandibular molars. CS group showed higher fracture strength values than VS and EM groups, so that the null hypothesis was rejected. To the extent of authors' knowledge, only a few studies have evaluated different kind of CAD/CAM blocks in the means of fracture strength and no study investigated different CEREC Omnicam endocrowns' mechanical properties.[19-21]

Resin nanoceramic group demonstrated the highest fracture strengths in a study which compared different CAD/CAM blocks with different elasticity modulus for endocrown restorations.[15] This investigation found that there was no statistically significant difference between the feldspathic and the lithium disilicate reinforced glass ceramic.[15] Similarly, in the present study, the resin nanoceramic endocrowns showed higher fracture strengths than lithium disilicate reinforced glass ceramic endocowns. In addition, El-Damanhoury et al. reported that all failures were repairable in resin nanoceramic group, however the load was applied at 35 degrees to long axis of the teeth in this study.[15] Their results showed that 70% failures were unrepairable in the lithium disilicate endocrowns. Aktas et al. demonstrated that various CAD/CAM materials with different elastic modulus showed no significant difference statistically regarding the fracture strength of endocrowns.[22] In this study, the zirconia reinforced ceramic and resin nanoceramic groups showed mostly unrepairable failures. Fracture patterns of teeth restored with endocrowns is crucial, because the remaining tissue should be retrievable for restoration.[22] The amount of lost fractured structure affects the clinician's decision for extraction. The fracture types should be repairable to be able to keep restoring the remaining structures and avoid extraction. Teeth with root-canal treatment are susceptible to catastrophic subgingival fractures. Most of the teeth showed unrepairable fractures under the cemento-enamel junction in the present study. However, the loads applied in the laboratory tests are much higher than masticatory forces, so that data in a clinical study report would be more significant. In a clinical study, 99 endocrowns were evaluated after 10 years and only one restoration was reported lost because of major fractures (total failures were 10).[23] Although, the resin nanoceramic used in the present study had an elastic modulus similar to dentin, the failure modes were mostly catastrophic. Therefore, it can be suggested that the remaining structure and root-canal involvement may cause unrepairable fractures.

CAD/CAM systems have been developed to obtain a precise marginal adaptation and smaller marginal gap in reduced time with better mechanical properties.[24] Endocrown restorations can be manufactured easier than conventional post-core systems due to fewer steps, with the advantages of CAD/CAM systems.[9] The developments and improvements in digital dentistry also leads to the presentation of new ceramic materials with different mechanical and esthetic properties.[25] Various kinds of ceramic blocks are available for CAD/CAM systems, such as feldspatic, leucite reinforced, lithium disilicate reinforced and zirconia ceramics. Feldspathic ceramics have been used in dentistry for a long time and leucite reinforced ceramics were manufactured to provide a better esthetic appearance. Lithium disilicate reinforced ceramics were developed to enhance fracture strength of restorations. On the other hand, zirconia ceramics are preferred to eliminate the chipping of ceramics with better esthetic outcome.[26] In recent years, ceramics and composite resins are combined and blocks such as resin nanoceramics ceramics have been developed to enable stress absorbance.[27] An *in vitro* study found that the flexural strength of a lithium disilicate reinforced glass ceramic was higher than a resin nanoceramic and a feldspathic ceramic.[28] Also, Albero et al. reported that lithium disilicate reinforced glass ceramics exhibited better mechanical properties than two different resin nanoceramics (Vita Enamic, Lava Ultimate).[29] However, in this investigation, ceramic bars were tested for mechanical properties and teeth were not restored with endocrowns. On the other hand, in the present study, resin nanoceramic (Cerasmart) endocrowns showed better fracture strength values than the lithium disilicate reinforced glass ceramic (IPS e.max CAD) endocrowns. Although lithium disilicate reinforced glass ceramics are shown to have better mechanical properties, the fracture strength of resin nanoceramics endocrowns have better results due to their similar elasticity modulus to dentin structure and lower elasticity modulus values than lithium disilicate reinforced glass ceramic materials in the present study.

In an *in vitro* study, Forberger and Göhring. reported that lithium disilicate endocrowns demonstrate similar fracture strengths with crowns placed after zirconia post placement.[30] In this investigation, endocrowns showed 50% repairable fractures whereas in the present study, most endocrown restorations exhibited unrepairable failures. Chang et al. compared the fracture strength of a post-core/crown and a ceramic (feldspathic) endocrown fabricated using CEREC 3D and found that endocrowns showed similar fracture strengths with post-core/crowns.[31] Failure possibility for endodontically treated premolars with MOD preparations using three CEREC ceramic restoration configuration was reported to be similar among MOD inlay, endocrown (buccal and lingual walls not prepared, only cusps reduced) and crown preparations.[32]

In a systematic review, it was reported that endocrowns exhibited a success rate between 94-100% in clinical trials.[30] On the other hand, 2 of the clinical trials mentioned in this review were preliminary studies with 6-month and 12-month follow-up periods.[33,34] In another clinical study, Bindl and Mörmann reported that feldspathic ceramic endocrowns showed good results after 2-year evaluation.[9] Clinical quality of the feldspathic ceramic endocrowns was approved. However, a clinical trial reported that endocrowns in molars exhibited similar fracture strengths with conventional crowns, but in premolars, endocrowns showed inadequate results.[33] Endocrowns for premolars were stated to be unacceptable due to 68.8% survival rate. However, classic crowns exhibited 94.6% survival rate.[35]

The most important limitation of this study was the high fracture loads applied by the testing machine. Mastication forces are not in consistent with these high loads, so that a clinical trial with the tested ceramics should be conducted and results should be reported. In addition, only one type of cavity preparation was used, so different preparation designs should also be tested to understand the potential of these ceramics.

CONCLUSION

Resin nanoceramic endocrowns using CEREC Omnicam system provided higher fracture strengths than all-ceramic endocrowns. Zirconia reinforced ceramic endocrowns and lithium disilicate endocrowns showed similar fracture strength values. The ceramics tested in the study exhibited similar fracture patterns which were mostly unrepairable.

Source of Finance

This study was supported by Hacettepe University Scientific Research Coordination Unit (Project ID: 8400).

Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

***Idea/Concept:** Şükran Bolay, Burcu Altun; **Design:** Şükran Bolay, Burcu Altun; **Control/Supervision:** Şükran Bolay; **Data Collection and/or Processing:** Burcu Altun, Fatma Dilşad Öz; **Analysis and/or Interpretation:** Şükran Bolay, Burcu Altun, Fatma Dilşad Öz; **Literature Review:** Burcu Altun, Fatma Dilşad Öz; **Writing the Article:** Burcu Altun, Fatma Dilşad Öz; **Critical Review:** Şükran Bolay, Fatma Dilşad Öz.*

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