Submitted: 01 February, 2024 Accepted: 15 March, 2024 Published: 03 September, 2024 DOI:10.22514/jocpd.2024.120

Journal of Clinical Pediatric Dentistry

CASE REPORT

A severely damaged premolar tooth restored with coronal pulpotomy and a 3D-printed endocrown

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Abstract

Advances in computer-aided design/computer-aided manufacturing (CAD-CAM) technologies and adhesives have enabled the use of endocrowns as an effective and conservative treatment option for restoring endodontically treated teeth in pediatric populations. Thus, this case report presents the treatment of a severely damaged premolar tooth with coronal pulpotomy and a 3D-printed endocrown restoration. A 13-year-old patient with pain due to profound caries in the left maxillary second premolar tooth was referred to the Department of Pediatric Dentistry at Gazi University in Ankara, Türkiye. Deep dentinal caries and severe tissue loss were revealed in the clinical examination. No periradicular lesions were detected in a radiographic examination, and there was no inflammation in the pulp. The selected intervention was a two-step process involving a coronal pulpotomy followed by a custom 3D-printed endocrown restoration. No clinical complications or radiographic pathologies were observed over a two-year follow-up period, and the patient was satisfied with the final esthetics and function of the restoration. 3D-printing technology can be successfully integrated into pediatric restorative dentistry and offers a conservative, efficient, and esthetically pleasing treatment option for children with severely damaged dentition.

Keywords

3D-printing; Additive manufacturing; CAD-CAM; Digital dentistry; Endocrown

1. Introduction

The restoration of the tooth is a critical aspect of endodontic treatments. In particular, immediate restorations are imperative for teeth undergoing vital pulp therapy (VPT) to ensure the treatment's long-term success [1]. Researchers have noted a significantly higher success rate in teeth undergoing VPT when calcium silicate cement (CSC) is used as the primary sealing material and a long-term restoration is immediately applied [2–5]. The most important advantages of an immediate restoration include the prevention of microleakage and the preservation of biomaterial. It has been reported that such a restoration will establish a basis for cuspal coverage restoration when necessary. However, assessing whether a tooth is ready for a definitive restoration after completion of VPT necessitates an appropriate waiting period. Time should elapse before additional tooth preparations are conducted for definitive (cuspal coverage) restoration in light of the tooth's symptoms and susceptibility to fracture [1].

An appropriate and well-placed definitive restoration should be considered an essential component of the vital pulpotomy procedure. Studies have shown that the type and quality of coronal restoration of pulpotomies are significantly correlated with the success of the treatment [6, 7]. After endodontic treatment, posterior teeth require adequate and full-coverage restorations, and such restorations should be used to reduce the risk of fractures, provide a coronal seal that prevents bacterial infection, and restore function [8, 9]. Stainless steel crowns (SSCs) are the most popular choice of restoration for young permanent first molars treated endodontically. According to the American Academy of Pediatric Dentistry (AAPD) [10], SSCs are indicated for the restoration of permanent teeth following pulpotomy or pulpectomy. However, restorations of permanent molars are interim restorations that must be replaced by full-coverage crowns [9, 10].

Given improvements in adhesive dentistry and the introduction of new materials with high-mechanical-strength properties, endocrown restorations have been developed to restore severely damaged teeth [11, 12]. Compared with conventional crowns, endocrown restorations, which have minimally invasive preparations and maximal tissue conservation, ensure the structural strength of a tooth by preserving the integrity of the remaining tooth tissue. Additionally, the design of endocrowns requires less fabrication time compared with conventional crowns [13, 14]. While the pulp chamber walls provide macro-retention, the adhesive cementation of the restoration provides micromechanical retention. That situation allows endocrowns to function as monoblock restorations [15]. Due to their monoblock structure and high fracture resistance, endocrowns reduce stresses occurring in the enamel, dentin, and cement layers. Developments in CAD-CAM technologies and materials science have enabled endocrown restorations to be fabricated using a variety of materials [14, 16, 17].

Recent developments in digital dentistry have revolved around three-dimensional (3D) printing technologies, and dental-related uses of this technology are increasing in prevalence. This technology is used in many fields of dentistry (*e.g.*, esthetic pediatric dental crowns and space maintainers, surgical guides, splints and educational models for pediatric dentistry) [18–21]. Unlike subtractive manufacturing (*i.e.*, milling) technology, 3D dental restorations are produced with additive manufacturing technology; that is, the production process is carried out by consuming less material via a layering technique [22]. 3D-printing technology has advantages over conventional techniques, given its high accuracy and ability to repeat the production process when necessary since the data are recorded. Many people believe this technology is more efficient than traditional technologies and furthermore reduces costs and lowers the incidence of errors [17]. A recent study evaluated the marginal and internal gaps of resin-based milled and 3D-printed crowns for primary teeth designed with different software programs using microcomputed tomography; the authors reported that all of the tested groups exhibited clinically acceptable gap values [23].

Recent studies have reported that composite restorations fabricated using 3D-printing have elasticity moduli that resemble those of natural dentin [22, 24]. In this case report, we focus on a second premolar with profound caries treated first with a coronal pulpotomy and then endocrown restoration with 3D-printing technology [25]. The 3D-printed restoration is preferred because of the advantages of 3D-printing technology (*i.e.*, reductions in material waste of up to 40%, reductions in time, and reduced costs compared with milled restorations. This case report describes procedures of this new technology that are useful for clinical practice.

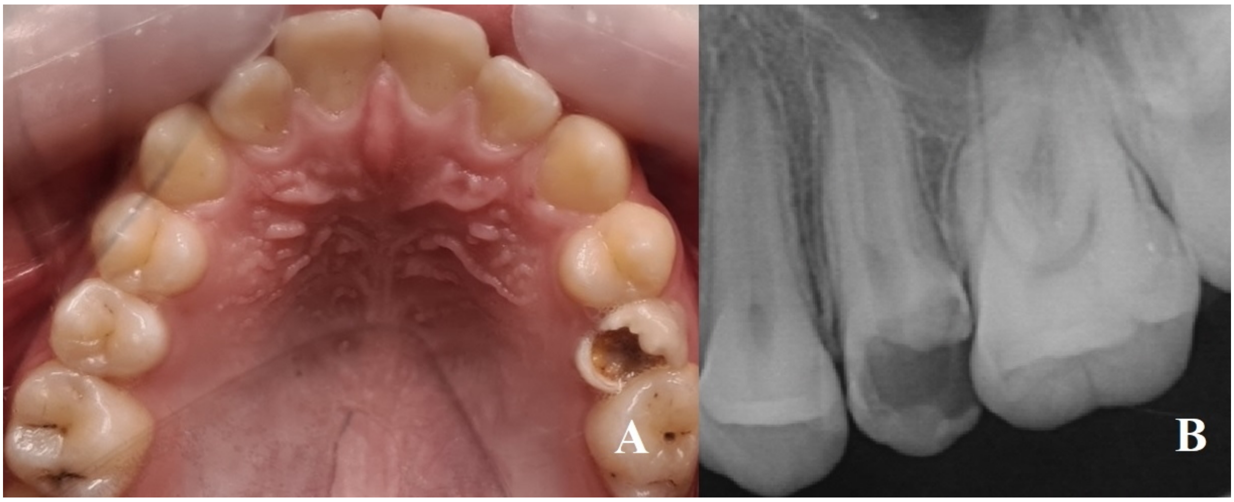
2. Case report

A 13-year-old boy in good general health sought dental care at the Department of Pediatric Dentistry, Faculty of Dentistry, Gazi University in Ankara, Türkiye. His chief complaint was pain in the left maxillary region that started after he ate sugary foods; that pain resolved itself in a short amount. Deep dentinal caries in the left maxillary second premolar tooth were observed upon clinical examination, and the patient's tissue loss in this tooth was severe (Fig. 1A). The patient had a Class I molar relationship, and his oral hygiene was poor. A radiographic examination revealed no periradicular lesion and uniform periradicular bone (Fig. 1B). Electric pulp testing (Digitest II, Parkell, Edgewood, NY, USA) and cold stimulus testing (Roeko Endo Frost, Coltene Whaledent AG, Altstätten, Switzerland) were applied to assess the status of the pulp; a positive response was noted. As a result of the negative response to the percussion test applied in addition to the pulp sensitivity test, we concluded that the pulp was not inflamed. The proposed treatment plan consisted of two steps. First, a coronal pulpotomy of a permanent maxillary right premolar tooth would be conducted. Next, an endocrown restoration was planned as a dental restoration because the remaining tooth structure was limited. The treatment plan was explained to the patient's parents, and the treatment plan was accepted by both the patient and his family. Written consent was obtained for the treatment.

After conducting the clinical and radiographic examinations, the patient's tooth was anesthetized using articaine with an adrenaline solution in a 1:200,000 (Maxicaine, Vem, İstanbul, Türkiye) ratio. The tooth was isolated with a rubber dam. The crown was then disinfected with 5% sodium hypochlorite. Complete caries were removed using a rounded burr on a low-speed hand-piece. A coronal pulpotomy was performed next to the level of the canal orifice using a sterile high-speed fissure diamond burr under water cooling. An access cavity was accordingly created. Pulp vitality was confirmed via the presence of hemorrhage, and hemostasis was achieved by applying a cotton pellet moistened with a 2.5% sodium hypochlorite solution for 5 minutes. White mineral trioxide aggregate (WMTA) (ProRoot, Dentsply, Tulsa Dental, OK, USA) was prepared according to the manufacturer's instructions. The WMTA was placed in a 4 mm-thick layer above the pulp tissue, and an intraoral radiograph was taken to confirm its correct placement (Fig. 2). A moistened cotton pellet was placed in the access cavity, and glass ionomer cement (Ketac Molar Easymix, 3M ESPE, St Paul, Minn.) was inserted as an interim restoration.

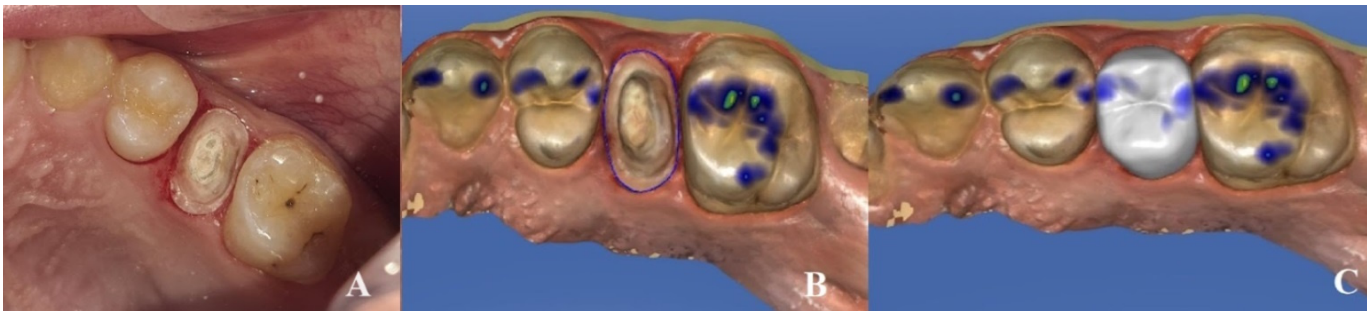
On the patient's second visit, the clinical findings were analyzed. We found that the patient's tooth was asymptomatic; therefore, the interim filling was removed. We also noted that the WMTA had successfully been set. Endocrown preparation was limited to the removal of the pulp chamber, excessively retentive areas, and alignment of the pulpal walls. The canal was deepened by 5 mm to fit 3 mm into the root [26]. The central anchorage of the pulpotomized tooth's endocrown was sited within the pulp chamber, undercuts were eliminated from the pulpal walls, and the base of the pulp chamber was flattened (Fig. 3A). A layer of resin-reinforced glass ionomer restorative material (Fuji II LC, GC Corporation, Tokyo, Japan) was placed directly over the MTA to protect the bioceramic material (Fig. 3B). Precise digital impressions of the prepared tooth, opposing arch, and buccal bite occlusion were acquired using an intraoral optical scanner (Cerec Omnicam; Dentsply Sirona, Bensheim, Germany), and virtual models were created (Fig. 3B). The endocrown was designed virtually using software (Cerec SW 4.4.4, Dentsply Sirona, USA) (Fig. 3C). The crown's design was converted to a Standard Triangulation Language (STL) file format for the 3D-printing process. The file was sent to the laboratory in order to produce the restoration with a 3D-printer. A restoration color of A2 on the Vita Classical Scale (VITA Zahnfabrik, Bad Sackingen, Germany) was selected.

The STL file was imported into a software program (PreForm 3.22.0, Formlabs Inc, Somerville, MA, USA) to automate the construction of the support structures. The endocrown was printed using definitive crown resin (Permanent Crown Resin; Formlabs Inc) with a 3D-printer (Formlabs Form 3B; Formlabs Inc, Somerville, MA, USA). The endocrown was cleaned with isopropyl alcohol for 3 minutes after fabrication using the washing unit (FormWash; Formlabs Inc) of the 3D-printer; the goal of the cleaning procedure was to



F I G U R E 1. Preoperative intraoral and radiographic views of the patient. (A) Preoperative intraoral view. (B) Preoperative radiographic view.

F I G U R E 2. Intraoral radiograph of the inserted WMTA.



F I G U R E 3. Endocrown restoration steps of the tooth. (A) Intraoral view after tooth preparation. (B) The virtual model with the prepared tooth. (C) The designed endocrown restoration.

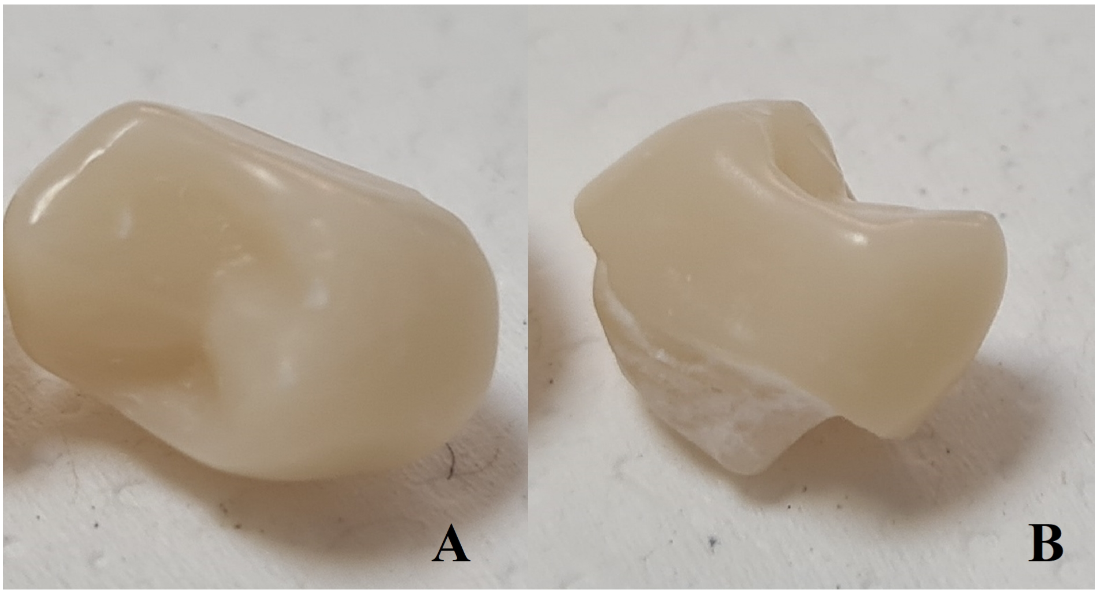


FIGURE 4. 3D-printed endocrown after mechanical polishing. (A) Occlusal surface and (B) inner surface.

remove any unpolymerized resin. The restoration was next subjected to a polymerization phase in the curing unit of the 3D-printer (FormCure; Formlabs Inc, Somerville, MA, USA). After polymerization, the structural supports were removed, and the intaglio surface of the endocrown was airborne-particle abraded to eliminate any residual particles. We then conducted an additional post-polymerization stage that involved exposing the endocrown to a temperature of 60 °C for 20 minutes within the same curing device.

Surface finishing was performed according to the manufacturer's recommendations (Fig. 4A,B). We then checked the occlusal interferences and marginal compatibility of the restoration. A bonding agent (Scotchbond Universal Plus, 3M ESPE) was applied to the prepared tooth surface and polymerized by a light-emitting diode (LED) curing device (Valo, Ultradent, South Jordan, UT, USA). We cemented the inner surface of the restoration in accordance with the manufacturer's recommendations. Prior to cementation, the endocrown was airborne-particle abraded with 50 μm Al_2O_3 particles with a sandblasting device for 20 seconds and then cleaned in an ultrasonic cleaner. The inner surface of the endocrown was silanized (G-Multi Primer; GC, Tokyo, Japan) air dried. Then the endocrown was cemented using dual-cured adhesive resin cement (G-CEM LinkForce GC, Tokyo, Japan). The endocrown surface was cured for 3 seconds, the excess cement was removed, and all surfaces were cured for 20 seconds each (Fig. 5A). A post-operative periapical radiograph was obtained after the placement of the restoration (Fig. 5B).

Regular clinical and radiographic follow-ups were conducted every six months over the course of two years (Fig. 6). The clinical examinations included evaluations of sensitivity to percussion and palpation, soft-tissue pathology, and marginal integrity of the endocrown restoration; the radiographic examination included evaluation of apical closure and periradicular lesions. No adverse clinical or radiographic findings were observed over a follow-up period. We concluded that the 3D-printed endocrown restoration achieved the same esthetics and functionality as the patient's permanent premolar teeth.

3. Discussion

The introduction of advanced digital dentistry techniques, including restorative procedures, into pediatric dentistry has opened up new fields for pediatric dentists. With advances in CAD-CAM technologies and adhesives, endocrown restorations give pediatric dentists an effective and conservative treatment option to restore endodontically treated teeth. Endocrowns have gained clinical acceptance for restoring endodontically treated teeth in adults, and their use is also considered suitable for pediatric patients [9, 27]. To the best of our knowledge, although there are a limited number of studies in the literature on the application of endocrowns in children [9, 28], there have been no studies pertaining to the use of 3D-printing technology to create endocrowns for children.

Coronal pulpotomy, a vital pulp treatment, is used in children for treating permanent teeth exposed to caries. The aims of this treatment include (a) preserving pulp vitality, (b) promoting root maturation, and (c) preserving the functional tooth in the dental arch [29]. Clinical prospective studies of patients with young permanent teeth have reported that coronal pulpotomy treatments with calcium silicate-based cement have been 100% successful after one year [30, 31]. Given the pronounced success of coronal pulpotomy, this treatment is an alternative to root canal therapy for treating cariously exposed permanent teeth [29, 32].

Earlier studies have reported that the outcomes of coronal pulpotomy treatment can be affected by various prognostic factors (*e.g.*, the type of definitive restoration) [29, 31]. Direct posterior composite resins are widely used for teeth with coronal pulpotomy. However, these resins have drawbacks (*e.g.*, polymerization shrinkage, which causes microleakage, cuspal distortion, crack formation, and wear) [28]. To overcome these problems, indirect restorations have been developed.

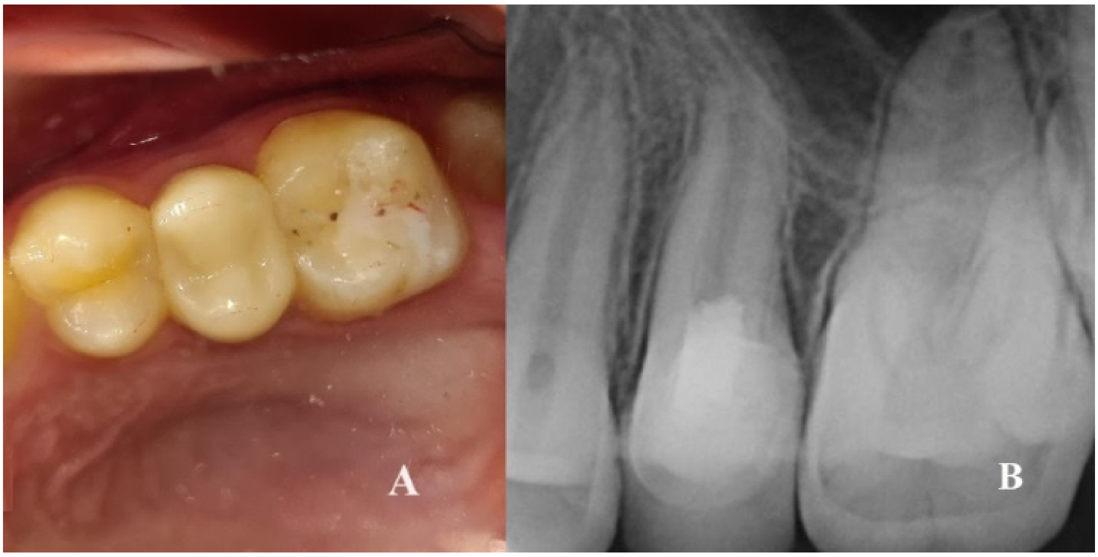


FIGURE 5. 3D-printed endocrown restoration. (A) Intraoral view of the endocrown after cementation. (B) Post-operative radiograph of the endocrown.

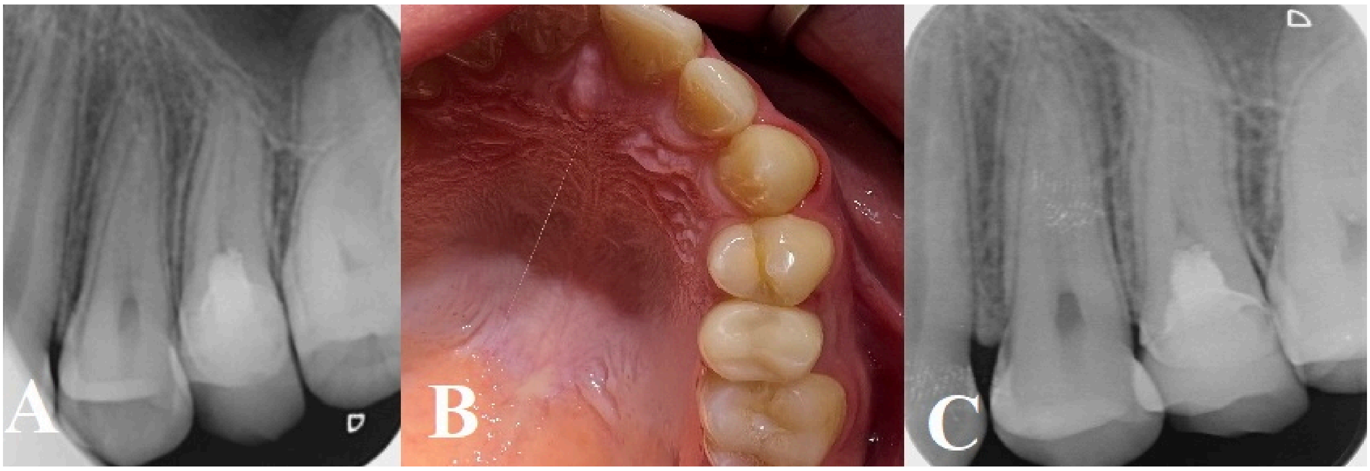


FIGURE 6. 3D-printed endocrown follow-up views. (A) 1-year follow-up radiograph. (B) 2-year follow-up intraoral view. (C) 2-year follow-up radiograph.

Prefabricated SSCs and zirconia crowns can be used for the treatment of such teeth. However, these types of restorations require removing the more coronal structures, and the marginal and internal adaptation of these prefabricated crowns have been questioned. On the other hand, the supragingival location of the crown margins impairs periodontal health. Therefore, special attention must be paid to the adaptation and finishing of an endocrown. These restorations for permanent molars are interim and must be replaced after adolescence by a full-coverage crown [10, 33]. Recently, CAD-CAM technologies have experienced a recent surge in popularity, and developments in restorative materials science have enabled the use of adhesively cemented endocrowns rather than prefabricated or custom crowns [34]. In the present case report, we reported a permanent maxillary right premolar tooth treated with coronal pulpotomy and a 3D-printed endocrown. The follow-up period was two years, and any biological, functional, and esthetical failures were not reported. The patient was also satisfied with the final result.

Both the preparation geometry and the restorative material play a role in the success of an endocrown restoration. Such restorations can be used in particularly endodontically treated teeth when the crown height is limited or in root canals that are calcified, curved, or narrow. However, endocrowns are furthermore an alternative treatment option for teeth treated with coronal pulpotomies. Irrespective of the clinical situation, the preparation design is characterized by a few basic principles. If the height of the pulpal chamber is less than 3 mm and the width of the cervical margin is less than 2 mm, endocrowns are not recommended. That is because the retention and stability of an endocrown are dictated by the dimensions of the pulpal chamber [35]. Silva-Sousa *et al.* [36] investigated the mechanical performance of endocrowns restored using different extensions within the pulp chamber. Those authors concluded that the larger extensions yielded improved mechanical performance. On the other hand, removing too much tissue from the chamber walls can reduce the thickness of the enamel [35]. Premolar endocrowns have also been reported to be less successful than molar endocrowns because there is less tooth surface for adhesion [37]. Although an endocrown restoration was used for a permanent maxillary right premolar tooth in this case report, mechanical failures such as decementation and tooth and restoration fractures were not observed during the follow-up period. The mechanical stability of the crown might be due to the fact that the preparation depth of the pulpal chamber was approximately at least 3 mm and the fact that restoration was precisely cemented using the manufacturer's adhesive-cementation protocol.

Various materials, such as composite resins and CAD-CAM produced materials, can be used for endocrown restorations [38]. El-Damanhoury *et al.* [39] investigated the fracture resistance of feldspathic, lithium disilicate and resin matrix ceramic endocrowns and found that resin matrix ceramic endocrowns were more fracture resistant. Selecting the correct material for endocrown restoration in children is important to ensure the success of the restoration. Deulkar *et al.* [38] presented two different cases of trauma-exposed anterior teeth in children that were successfully addressed using endocrowns fabricated with composite and lithium disilicate prostheses. In another case report, Bilgin *et al.* [28] presented a successful treatment of a 7-year-old patient with a resin matrix ceramic endocrown restoration produced using CAD-CAM. These case reports reveal that customized resin-containing restorations may be beneficial for the treatment of pediatric patients; such restorations have similar physical and mechanical properties to natural tooth structures. Furthermore, the lower modulus of elasticity resin-containing materials absorbs occlusal stresses and reduces the effect of occlusal forces [33].

In this case report, we have presented the successful treatment of a permanent maxillary right premolar tooth with coronal pulpotomy and a 3D-printed resin endocrown restoration. However, there is still a relative dearth of information about 3D-printed endocrowns in pediatric populations. In order to recommend the clinical use of 3D-printed endocrowns in pediatric patients and to predict the long-term outcomes of these restorations, randomized controlled clinical studies are necessary.

4. Conclusions

The satisfactory results of our approach, demonstrated over a two-year follow-up period, highlight the potential of 3D-printing technology for developing restorative applications in pediatric populations. Our findings highlight a conservative, effective and esthetically pleasant treatment option for children suffering from dental problems.

ABBREVIATIONS

VPT, vital pulp therapy; CSC, calcium silicate cement; SSCs, stainless steel crowns; AAPD, American Academy of Pediatric Dentistry; CAD/CAM, Computer-aided design/Computer-aided manufacturing; 3D, three-dimensional; WMTA, White Mineral Trioxide Aggregate; STL, Standard Triangulation Language.

AVAILABILITY OF DATA AND MATERIALS

The data are contained within this article.

AUTHOR CONTRIBUTIONS

GNY and NA—made contributions to the implementation of endodontic treatment and arranged the patient's follow-up sessions. CBİ and MBG—made contributions and assistance in the restoration preparation, digital impression, and cementation. NA and MBG—wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Written patient's consent to participate was obtained for the treatment by both the patient and his family. Ethical approval for this study has been waived by the Ethics committee of Gazi University.

ACKNOWLEDGMENT

The authors wish to extend their sincere gratitude to Btech Innovation for their invaluable contribution to the production of endocrown restoration in our study.

FUNDING

This research received no external funding.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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How to cite this article: Gamze Nazlı Yanar, Ceyda Başak İnal, Nagehan Aktaş, Merve Bankoğlu Güngör. A severely damaged premolar tooth restored with coronal pulpotomy and a 3D-printed endocrown. Journal of Clinical Pediatric Dentistry. 2024; 48(5): 193-199. doi: 10.22514/jocpd.2024.120.