EFFECT OF PROXIMAL CARIES DRIVEN ACCESS ON THE BIOMECHANICAL BEHAVIOR OF ENDODONTICALLY TREATED MAXILLARY PREMOLARS

Sumedha Sumbria[1], Anisha Kulkarni[2], Rakshina Siddiqui[3], Shruti Nayak[4]

Article History: Received: 15.04.2023 **Revised:** 01.06.2023 **Accepted:** 15.07.2023

Abstract

Introduction: - Endodontic therapy is usually indicated as a consequence of an extensive carious process or dental trauma, both leading to substantial tooth tissue loss.

[1]Department of Conservative Dentistry and Endodontics, Rama Dental College, Hospital & Research Centre, Kanpur
[2]Department of Conservative Dentistry and Endodontics, Government College of Dentistry, Indore
[3] Consultant Endodontist, Royal Dental Clinic, Mandsaur
[4]Department of Conservative Dentistry and Endodontics, ESIC Dental College, Kalaburgi

DOI: 10.31838/ecb/2023.12.s3.854

1. Introduction

Endodontic therapy is usually indicated as a consequence of an extensive carious process or dental trauma, both leading to substantial tooth tissue loss. Tissue loss has been appointed the main cause of deterioration of the biomechanical properties of endodontically treated teeth, particularly the loss of proximal ridges and access cavity preparation. The definitive restoration of an endodontically treated tooth is of utmost importance for tooth survival and for the restitution of its biomechanical properties. Full crowns made of metal-ceramic or all-ceramic material have historically been utilised, frequently with a post as an extra retention measure6. On the survival of endodontically treated premolars, multiple studies found a beneficial effect of post implantation. This is especially true for teeth that lack coronal walls but exhibit a ferrule effect. Therefore, the application of a post in teeth that present coronal walls should be carefully examined in order to conform with the inclination towards procedural simplification and tooth tissue preservation. There has been a shift in recent years towards less invasive restorative procedures—Prevention of Extension rather than Extension for Prevention—in the era of minimally invasive dentistry.

In comparison to indirect ceramic restorations, resin composites and adhesive systems can offer comparable fracture resistance and clinical survival due to significant advancements made since their initial introduction to the dental industry. Composite restorations have the advantage of being more affordable and repairable than ceramic ones.

Chair-side treatments known as CAD/CAM indirect restorations, which decrease laboratories time and costs, are getting more common in daily clinical practice.[18] Endocrown, which was developed more than 20 years ago[19], in particular, appears to be comparable to full crown restorations in terms of the survival rates of teeth and resistance to fracture, particularly in molars. It has also demonstrated encouraging outcomes in regards of longevity and ease of production. However, endo-crowns seem to fail more frequently in premolars. Hence, it is important to further investigate the causes underlying the more unpredictable clinical performance of endo-crowns in premolars compared to molars.

It is recommended to retrieve in vitro and FEA data on an issue in question first because to the difficulty and ethical concerns of clinical investigations. A common technique in dentistry is finite element analysis (FEA), which offers a wide range of opportunities to test materials and restorative solutions and can, to a large extent, be extrapolated to the clinical setting23,24. Alveolar bone and the periodontal ligament (PDL) are modelled in the FEA to replicate the biomechanical behaviour of tooth tissues. The design of the FEA study and the in vitro validation differ in terms of assisting tissue modelling, according to a recent assessment of FEA studies verified through in vitro studies.[25] While teeth were placed in epoxy resin, composite resin, or silicone[25] in the in vitro investigations, alveolar bone and/or PDL were mimicked in the FEA. This might have significantly increased the variability of the research' findings. To the authors' knowledge, the literature has not yet addressed this crucial issue.

Thus, the current study's objectives were to investigate the von Mises stresses and equivalent strains in an upper second premolar that had undergone endodontic treatment but had no remaining coronal walls restored using (a) DR, (b) CAD/CAM EC, or (c) CAD/CAM C through the use of FEA, and to validate the 3-D model of an upper second premolar that had undergone endodontic treatment via an in vitro static fracture examination. Another goal was to find out if simulating supporting tissue, such as alveolar bone and PDL (B) or PMMA, affected the outcomes of the FEA tests. The null hypotheses had been that (1) the type of restoration has no bearing on von Mises stress and equivalent strain values in restorative substances or dental tissues; (2) the kind of restoration has no bearing on von Mises stress and equivalent strain distribution in restorative materials or dental tissues; (3) supporting tissue modelling has no bearing on von Mises stress and equivalent strain values in restorative content or dental tissues; and (4) supporting tissue

2. Methodology

FEA. The upper second premolar that was excised for orthodontic purposes with the patient's informed consent was scanned using computed tomography to construct the three-dimensional tooth model that was employed in the current investigation.).

Investigation was conducted in line with the Helsinki Declaration at [1]Department of Conservative Dentistry and Endodontics, Rama Dental College, Hospital & Research Centre, Kanpur. A thorough description of the model creation process may be found elsewhere.[3,4] In a nutshell, 42 sections in the z-axis were uploaded to a segmentation program in the DICOM protocol and depicted dental tissues. The separation was carried out on the basis of the variations in signal density between various tooth tissues. The enamel, dentin, and pulp solid bodies were made using the revised shapes of the dental tissues that had been loaded into modelling software. Following the construction of the basic tooth model, an endodontic procedure using rotary instruments (size 25 and taper of 0.6 of the endodontic instrument was simulated) and gutta-percha filling was performed on a transversal tooth portion that was 2 mm above the CEJ (ferrule effect). Further, three different restorative options were created (Fig. 5): Group 1 (DR, control): Direct composite restoration without a retentive cavity; Group 2 (EC): CAD/CAM composite endocrown with a 3 mm-deep intracanal portion and a 100 µm-thick layer of resin cement between the crown and the tooth tissues; Group 3 (C): A glass fiber composite post inserted 8 mm into the tooth canal, composite core, and CAD/CAM composite crown.

A 100 mm-thick coating of resin cement was modelled around the pillar and underneath the crown. Two distinct supporting tissue alternatives were modelled for each group, 2 mm below the level of the CEJ: (a) PDL, 0.2 mm thickness and alveolar bone (B); and (b) PMMA. As a result, six distinct models were used in the final evaluation: DRB, DRPMMA, ECB, ECPMMA, CB, and CPMMA. All dental tissues and materials were given material attributes, which included being linear, elastic, and isotropic (Table 1).

Table 1. Material Properties.

Material	**Young's modulus (MPa)**	**Poisson's ratio**	**References**
Enamel	84,100	0.20	59
Dentin	18,600	0.31	59
Periodontal ligament	70	0.45	59
Gutta-percha	100	0.49	60
Alveolar bone	15,000	0.30	59
ParaCore (Coltène/Whaledent, Altstätten, Switzerland)	7500	0.33	*
Composite resin blocks CAD/CAM Brilliant Crios (Coltène/Whaledent)	10,300	0.30	*
DuoCem (Coltène/Whaledent)	6500	0.33	*
ParaPost Taper Lux (Coltène/Whaledent)	45,000	0.30	*
Synergy D6 (Coltène/Whaledent)	9700	0.30	*
Polymethyl methacrylate	2770	0.35	†

To imitate the loading used in the in vitro fracture resistance tests, an axial load of 850 N was applied to 2 sites on the inner slopes of both cusps in the current investigation. On the exterior of the PMMA that simulates bone, the model was permanently fixed in all possible directions. Assumptions were made regarding perfect bonding between model components. A high-quality meshing method based on curvature was used to produce 87,467–146,189 elements and nodes ranging from 136,513-229,599 in number. For meshing, parabolic tetrahedral solid components were utilized as they allow for better meshing of objects with irregular shapes, like biological tissues. The largest element had a dimension of 2.30906 mm, while the smallest was 0.230906 mm. 95-96.5% of the elements had an aspect ratio lower than 3, whereas 0.0606–0.268% of them had a ratio larger than 10. Next, numerical analysis was carried out in Solidworks' "Simulation" add-in. Calculations and records of Von Mises stresses and equivalent strains were made.

Static Fracture Resistance Test: in Vitro Validation.

Unless otherwise noted, Coltène/Whaledent sponsored the dental supplies utilised in the current investigation. Two qualified doctors (T.M., A.C.) have used all the materials while completely adhering to the manufacturer's instructions.

15 extracted single-rooted premolars were chosen, handled endodontically with rotary instruments up to file size 25, and obturated with gutta-percha (sample size calculated using G*Power 3.1.9.7 for Windows: effect size f = 1.9191754, error probability = 0.050, power (1- error probability) = 0.800). After removing the crown and leaving 2 mm of healthy dentinal tissue in the cervical region above the CEJ, teeth were subsequently processed according to a routine procedure.

Premolars were assigned at random to one of three groups (n = 5) using the crown restoration methodology, which was done after the FEA groups: DR: (control)—Following the application of an adhesive resin (One Coat 7 Universal) and light-curing for 20 seconds under an LED curing light, selective enamel etching was carried out for 30 seconds using a 37% phosphoric acid solution (Etching). All restorative operations for all the specimens used the same curing equipment. Additionally, a 2 mm-thick layer of a direct resin composite restoration (Synergy D6) was stacked before being polymerized for 40 s on each layer. A transparent silicone mould was constructed before to the tooth's treatments in order to generate the occlusal anatomy. The composite was polymerized through the silicone mold for 40 s from each side, then the mold was removed, and the curing procedure was repeated.

EC: To make room for a CAD/CAM composite endo-crown (Block Brilliant Crios; crown wall thickness 5 mm) made with a milling system, three mm of the gutta-percha endodontic filling was removed from the tooth's cervical part. The crown's luting surface was treated with sandblasting for 20 seconds at 1,5 bar pressure using 50 m sodium bicarbonate particles, followed by 20 seconds of water washing, two seconds of air drying and five minutes in an ultrasonic bath with a 50% ethanol solution. Additionally, the composite crown and the tooth structure were coated in an adhesive resin. A dual cure resin cement (DuoCem) was used to fix the crown after the adhesive was light cured for 20 seconds solely on the tooth surface. The restoration's crown was light-cured from every surface in the final process.

C: The remaining coronal area of the tooth (cervical margin: 1 mm, occlusal thickness: 1.5–2 mm, axial wall thickness: 1-1.5 mm) was prepared for a composite crown. Teeth were rebuilt using a composite post made of glass fibre. Using a dual-cured resin-based luting substance (DuoCem), this post was then cemented 8 mm into the root canal and polymerized for 30 seconds using an LED curing device. The tooth structure was then covered with a composite build-up (ParaCore Dentin) utilising a self-etch adhesive process (Parabond with Non-Rinse Conditioner). This composite build-up was then polymerized for 60 seconds under an LED curing light. After the tooth had undergone the necessary preparation, a CAD/CAM composite crown was machined, sandblasted, luted with a dual cure resin-based luting cement (DuoCem) and a universal adhesive (One Coat 7 Universal), and polymerized for 20 seconds on each side, much like in the EC group.

Further, lateral static fracture resistance test was performed after 30-days storage in artificial saliva (KCl 0.9639 g/L, KSCN 0.1892 g/L, $Na_2SO_4 \cdot 10H_2O$ 0.763 g/L, NH_4Cl 0.178 g/L, $CaCl_2 \cdot 2H_2O$ 0.2278 g/L, $NaHCO_3$ 0.6308 g/L, $ZnCl_2$ 2.726 mg/L, HEPES 1.186 g/L, pH 7.4) at 37 °C. The teeth were placed in a universal test machine at a 45° angle to the long axis of the tooth, with the roots of the teeth (2 mm under the CEJ) immersed in methacrylate resin. The specimens were subjected to a vertical static load with a crosshead speed of 0.5 mm/min using a metal rod with a spherical tip that was 6.0 mm in diameter. Additionally, fractographical examination of the failure regions was carried out at a 30x magnification using a stereomicroscope. While the fractures above the CEJ were thought to be repairable, those that involved the CEJ or the tooth structure below it were not.

Since the normality (Shapiro–Wilk test), and homoscedasticity assumptions (modified Levene test) were notviolated, the data were statistically analyzed using a one-way ANOVA and post-hoc Bonferroni tests with the significance level set at α = 0.050.

3. Results

Maximum von Mises stress values
Table 1 displays the highest von Mises stresses for the models under investigation. While the maximal stresses in the restorations were discovered to be comparable across the groups, there were some discrepancies between the groups in the tooth tissues. Irrespective of the supporting tissue employed, the stresses in the dentin were lower in the indirect restorations compared to the direct restorations (DR > EC > C). The stresses in the enamel were marginally greater in all the models with the PMMA support and slightly higher in the EC in comparison to the DR. Higher strains were seen in the dentin and restorative materials in the root region of the C model in the B supported model as compared to the one immersed in PMMA.

Von Mises stresses distribution. The largest stress points were located in the same places on both cusps, the occlusal central fissure, and the cervical region of the enamel and dentin, notably the vestibular component, in the crowns of all the examined models. The stress distribution was similar between the DR and EC models, although there were some discrepancies between these two restoration types and the C models. The crown-restored models demonstrated a slightly smaller region under high loads in the cervical vestibular segment, despite the fact that the occlusal stress distribution in all the models was identical.

Interestingly, although the maximum stress values were similar, the distribution of stresses was different between the groups having B as supporting tissue, compared to the PMMA. There were larger areas of high stresses in the root portion of all the models supported by B. The most prominent differences can be noted in the CB model, where the highest stresses in dentin were not distributed at the cervical vestibular portion of the root as in the CPMMA and all the other investigated models, but were located on the bottom of the post cavity preparation while in the CPMMA model it was on the cervical vestibular portion of the root, similarly to all the other models.

Table 2. Maximum Von Mises stresses (MPa).

	Direct restoration		**Endocrown**		**Post, core and full crown**	
	Bone	**PMMA**	**Bone**	**PMMA**	**Bone**	**PMMA**
Crown restoration	735.3	735.4	736.1	736.0	731.1	731.1
Dentin	125.1	127.0	113.3	117.4	90.3	86.1
Enamel	230.6	236.4	256.0	261.6	–	–
Crown cement	–	–	38.5	38.6	60.2	62.8
Post	–	–	–	–	66.6	50.7
Post cement	–	–	–	–	27.5	18.0
Composite build-up	–	–	–	–	38.3	38.3

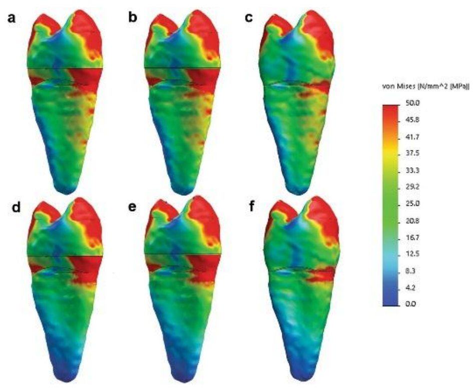


Figure 1. Von Mises stresses distribution: (a–c) models restored with DR, EC, and C, respectively, with periodontal ligament and bone as supporting tissue; (d–f) models restored with DR, EC, and C, respectively,with

polymethyl methacrylate as supporting tissue.

Static fracture resistance test: in vitro validation. There were no statistically significant differences in the static fracture test results between the three groups tested, according to the one-way ANOVA test findings provided in Table 3 ($p = 0.307$). Three different evaluators each used a stereomicroscope to assess the fracture mechanisms. The results showed that all of the teeth restored with an EC fractures were unrestorable, which was followed by 20% and 40% of restorable fractures in the C and the DR groups, respectively (Table 3). The findings demonstrated that the agreement among the evaluators was 100%. The in vitro research's results revealed that the teeth's failure started on the occlusal surface on the inner slope of the buccal cusp close to the central fissure and spread to the vestibular cervical portion of the tooth. This area of the teeth correlated to the high stress areas of the FEA model.

Table 2. Equivalent von Mises strain.

	Direct restoration		**Endocrown**		**Post, core and full crown**	
	Bone	**PMMA**	**Bone**	**PMMA**	**Bone**	**PMMA**
Crown restoration	0.05883	0.05884	0.05394	0.05394	0.05399	0.05399
Dentin	0.004501	0.004578	0.004452	0.004538	0.004065	0.003327
Enamel	0.004501	0.004578	0.001494	0.001508	–	–
Crown cement	–	–	0.004671	0.004662	0.006974	0.007185
Post	–	–	–	–	0.001179	0.0009019
Post cement	–	–	–	–	0.003413	0.002185
Composite build-up	–	–	–	–	0.004363	0.004364

4. Discussion

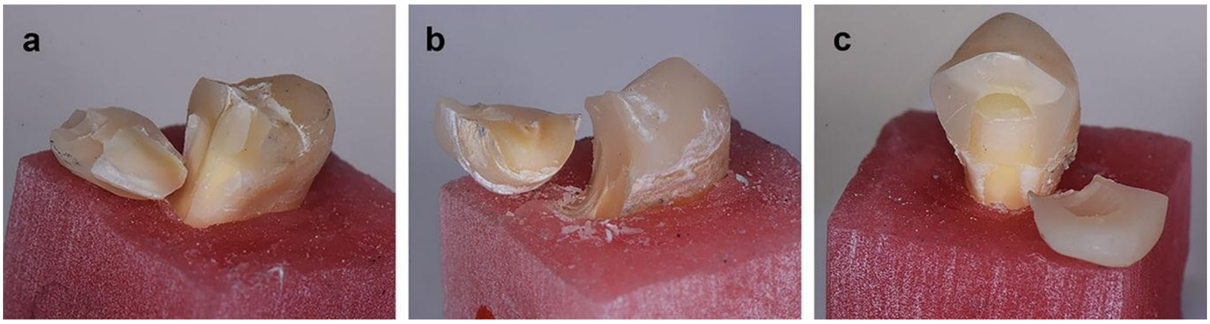
The current FEA study's findings showed that, depending on the kind of restoration and the modelling of the supporting tissue, the maximum von Mises stress and equivalent strain values in dental tissues and restorations varied across the groups under investigation. The first and third null hypotheses were thus disproven. Additionally, the kind of restoration and the modelling of the circumstances surrounding the tooth caused variations in the distribution of the maximum stresses in the dentin, which may have clinical implications. The second and fourth null hypotheses were therefore likewise disproved. In the coronal restorations of all the FEA models examined in the present investigation, maximum von Mises stresses and their distributions were comparable, although strains were slightly lower in the indirect restorations. This is consistent with the findings of the fracture resistance test since, despite the fact that the mean fracture resistance was lower in the DR group, there were no statistically significant differences between the tested groups. Although certain researchers found higher fracture resistance and lower stresses in premolars restored with endocrowns compared to the standard crowns28,29, these results are consistent with various FEA and in vitro studies14,26,27. Contrary to this, another study[30] showed lower survival rate of premolars restored with endocrowns.

While the literature's results stated above (14,26,27,28) are conflicting, a more thorough examination of the interactions between stress and strain values and distributions in the models used in the current study might provide useful information. First, compared to the DR and EC, crown-restored models displayed reduced von Mises stresses and similar dentin strains. Although this may imply that the post, core, and crown restoration could clinically demonstrate greater conservation of the dental tissues, it is important to take note of where the greatest pressures are present. Instead of the vestibular cervical region of the tooth as in the other analyzed groups, the CB group's maximal von Mises stresses in dentin could be observed near the bottom of the post preparation cavity. As shown in vitro, it appears that the post not only transferred some of the stresses to the tooth's root but also partially absorbed them. As a result, it may have the capacity to operate as a wedge and cause catastrophic tooth fracture. This is consistent with the finding that premolars restored with an endocrown experience less stress concentration on the inner wall of the root than those repaired with a post, core, and crown. In general, catastrophic root fractures occur more frequently in post, core, and crown restorations than in endocrowns.[22] Actually, clinical research has shown that post insertion can only significantly minimize the failure of post-endodontic restorations in highly impaired teeth (when no coronal walls are available)9. As a result, post placement may not be required in teeth with some dental tissues still extant. These statements are true for conventional FRC posts, however customised posts have become more common in recent years and may be able to retain the coronal restoration more effectively while still protecting the anatomy of the root canal and tooth tissue. It was shown in vitro that using auxiliary posts and/or composite resin relined posts could improve bond strength to root dentin, fracture strength, and failure structure, presumably as a result of a reduction in thickness and flaws. FEA generated stress distribution in incisors showed a more favorable pattern compared to traditional systems[28], but FEA studies in premolars on this issueare currently lacking.

Additionally, the crown cement in the EC models had approximately 35% lower von Mises stresses and strains than the cement in the C models, which is probably because these two types of crowns differ geometrically from one another. As previously demonstrated[27], Endocrown is a more substantial monolithic restoration that shields the underlying cement layer from the direct effects of occlusal stresses. This would suggest that complete crowns are more likely than endocrowns to debond. Additionally, the DR models' enamel stresses were a little bit lower than those of the EC models. The strains were, however, 3 times less prevalent in the enamel of the EC models. In actuality, the enamel in the DR models and the crown cement layer in the EC models both displayed a similar maximum strain value. Therefore, it appears that the cement layer "buffered" the strain of the enamel beneath the endocrown. This may be because the cement has a lower elastic modulus than the crown and the enamel, which may help the enamel tissue be preserved better during fatigue loading in teeth restored with endocrowns as opposed to direct restorations.[3]

The majority of samples in all groups failed the static fracture test in a consistent way, with the fracture most frequently reaching the cervical vestibular region of the dentin beneath the cement-enamel junction (CEJ) and starting at the inner slope of the buccal cusp, close to the central occlusal fissure. This failure mode lines up with earlier studies that have been published. When the models embedded in PMMA were subjected to a load that matched the mean fracture load in the static fracture resistance test, the current FEA analysis indicated a distribution of high stresses that was consistent with the fracture propagation of the in vitro investigation. The loading locations on the inner slopes of the cusps, the central fissure, and the cervical vestibular region of the tooth tissues were the areas subject to the highest stresses. Compared to the C restored model, the areas of high stresses were greater in the DR and EC restored models. It's interesting to note that when the PDL and the supporting bone tissue were modelled, the distribution of high stress sites in the dentin shifted. The root component of the teeth had bigger areas under moderate stresses, and in the C model, the area under greatest stress moved from the vestibular cervical portion to the base of the post-preparation cavity. Although the teeth in the in vitro validation trials were primarily embedded in epoxy resin, composite resin, or silicone, PDL and/or bone were simulated in the related FEA research, according to a recent review on validated FEA research in dentistry25. So far as the authors are aware, this is the first study to look into alternatives for supporting tissue that would be appropriate for both an in vivo and an in vitro experimental context.

Figure 4. Failure modes of the fractured teeth: (a) DR; (b) EC; (c) C.



5. References

1. Maravić, T. et al. Influence of restorative procedures on endodontically treated premolars: Finite element analysis of a CT-scan based three-dimensional model. Dent. Mater. J. 37, 493–500. (2018).
2. Kantardžić, I., Vasiljević, D., Lužanin, O.,

Maravić, T. & Blažić, L. Influence of the restorative procedure factors on stress values in premolar with MOD cavity: A finite element study. Med. Biol. Eng. Comput. 56, 1875–1886. (2018).

3. de Carvalho, M. A., Lazari, P. C., Gresnigt, M., Del Bel Cury, A. A. & Magne, P. Current options concerning the endodontically-treated teeth restoration with the adhesive approach. Braz. Oral Res. 32, 147–158. (2018).
4. Bitter, K. & Kielbassa, A. M. Post-endodontic restorations with adhesively luted fiber-reinforced composite post systems: A review.Am. J. Dent. 20, 353–360 (2007).
5. Ferrari, M. et al. A randomized controlled trial of endodontically treated and restored premolars. J. Dent. Res. 91, 72S-78S. 2012
6. Ferrari, M., Cagidiaco, M. C., Grandini, S., De Sanctis, M. & Goracci, C. Post placement affects survival of endodontically treated premolars. J. Dent. Res. 86, 729–734 (2007).
7. Bitter, K. et al. Randomized clinical trial comparing the effects of post placement on failure rate of postendodontic restorations: Preliminary results of a mean period of 32 months. J. Endod. 35, 1477–1482. (2009).
8. Burke, F. J. T. From extension for prevention to prevention of extension: (minimal intervention dentistry). Dent. Update 30, 492–502. (2003).
9. Van Meerbeek, B. et al. State of the art of self-etch adhesives. Dent. Mater. 27, 17–28. (2011).
10. Pashley, D. H. et al. State of the art etch-and-rinse adhesives. Dent. Mater. 27, 1–16. (2011).
11. Sedrez-Porto, J. A., Münchow, E. A., Valente, L. L., Cenci, M. S. & Pereira-Cenci, T. New material perspective for endocrown restorations: Effects on mechanical performance and fracture behavior. Braz. Oral Res. 33, e012. https://doi.org/10.1590/1807-3107b or-2019.vol33.0012 (2019).
12. Pedrollo Lise, D. et al. Biomechanical behavior of endodontically treated premolars using different preparation designs and CAD/ CAM materials. J. Dent. 59, 54–61. (2017).
13. Acar, D. H. & Kalyoncuoğlu, E. The fracture strength of endocrowns manufactured from different hybrid blocks under axial and lateral forces. Clin. Oral Investig. 25, 1889–1897. (2021).
14. Skupien, J. A. et al. Crown vs. composite for post-retained restorations: A randomized clinical trial. J. Dent. 48, 34–39. https://doi. org/10.1016/j.jdent.2016.03.007 (2016).
15. Skupien, J. A. et al. A practice-based study on the survival of restored endodontically treated teeth. J. Endod. 39, 1335–1340. https:// doi.org/10.1016/j.joen.2013.06.028 (2013).
16. Miyazaki, T., Hotta, Y., Kunii, J., Kuriyama, S. & Tamaki, Y. A review of dental CAD/CAM: Current status and future perspectives from 20 years of experience. Dent. Mater. J. 28, 44–56. https://doi.org/10.4012/dmj.28.44 (2009).
17. Pissis, P. Fabrication of a metal-free ceramic restoration utilizing the monobloc technique. Pract. Periodontics Aesthet. Dent. 7, 83–94 (1995).
18. Bindl, A. & Mörmann, W. H. Clinical evaluation of adhesively placed Cerec endo-crowns after 2 years–preliminary results. J. Adhes. Dent. 1, 255–265 (1999).
19. Bindl, A. & Mörmann, W. H. An up to 5-year clinical evaluation of posterior In-ceram CAD/CAM core crowns. Int. J. Prosthodont. 15, 451–456 (2002).
20. Govare, N. & Contrepois, M. Endocrowns: A systematic review. J. Prosthet. Dent. 123, 411-418.e9. (2020).
21. Ferrari, M., Breschi, L. & Grandini, S. Fiber Posts and Endodontically Treated Teeth: A Compendium of Scientific and Clinical Perspectives (Modern Dentistry Media, 2008).
22. Limjeerajarus, N. et al. Comparison of ultimate force revealed by compression tests on extracted first premolars and FEA with a true scale 3D multi-component tooth model based on a CBCT dataset. Clin. Oral Investig. 24, 211–220. (2020)
23. Richert, R. et al. Validated finite element models of premolars: A scoping review. Materials 13, 3280.
24. Lin, C.-L., Chang, Y.-H. & Pai, C.-A. Evaluation of failure risks in ceramic restorations for endodontically treated premolar with MOD preparation. Dent. Mater. 27, 431–438.
25. Forberger, N. & Göhring, T. N. Influence of the type of post and core on in vitro marginal continuity, fracture resistance, and fracture mode of lithia disilicate-based all-ceramic crowns. J. Prosthet. Dent. 100, 264–273.
26. Chang, C.-Y., Kuo, J.-S., Lin, Y.-S. & Chang, Y.-H. Fracture resistance and failure modes of CEREC endo-crowns and conventional post and core-supported CEREC crowns. J. Dent. Sci. 4, 110–117.
27. Lin, C.-L., Chang, Y.-H., Chang, C.-Y., Pai, C.-A. & Huang, S.-F. Finite element and Weibull analyses to estimate failure risks in the ceramic endocrown and classical crown for endodontically treated maxillary

premolar. Eur. J. Oral Sci. 118, 87–93.

28. Bindl, A., Richter, B. & Mörmann, W. H. Survival of ceramic computer-aided design / manufacturing crowns bonded to preparations with reduced macroretention geometry. Int. J. Prosthodont. 18, 219–224 (2005).

29. Gaintantzopoulou, M. D., Farmakis, E. T. & Eliades, G. C. Effect of load cycling on the fracture strength/mode of teeth restored with FRC posts or a FRC liner and a resin composite. Biomed Res. Int. 2018, 9054301.