

Endocrown Restorations on Endodontically Treated Premolars Teeth: A Review

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ABSTRACT

Root canal-treated premolars teeth have specific challenges due to their more brittle behavior compared to vital teeth, their tissue faults that happened throughout the preparations, and the risk of accidental root perforation while preparing a post space. In addition, intra-radicular posts have the disadvantage of removing the required sound tooth structure to fit the post into the root canal. Endocrowns, as one component, assemble the intra-radicular post and core-crown complex is an adhesive, less invasive preparation restorations. Mechanical and optical properties, less working and chair time consuming, and prices compared to the conventional methods are the benefits of endocrowns. Many studies indicated endocrown as an appropriate restoration choice for root canal-treated teeth, but there is no consensus in using this treatment in premolars; therefore, this study aims to describe a comprehensive review about the use of endocrown on severely damaged premolars.

Keywords

Endo crown, premolar, endocrown preparation, ferrule

Introduction

The management of root canal-treated teeth (RCTT) from the restorative view is a controversial subject widely discussed in the dental literature. Experimental philosophies have been led to clinical opinions on this approach because available scientific data had little connection with inconclusive clinical studies (D. Dietschi, O. Duc, I. Krejci, & A. Sadan, 2008); Sevimli, Cengiz, and Oruc (2015). RCTT from the biomechanical risk had a higher failure rate than vital teeth, and fracture of such teeth is a common problem in restorative dentistry (Zarone et al., 2006). Non vital teeth had extirpated pulp tissue along with less its adjacent dentin made their strength, with its characteristics defeat (Z. Zhu, Dong, He, Pan, & Tang, 2015). The restoration retention in such teeth is usually compromised; thus, it may be intra-radicular posts along with or without core required (Sarkis-Onofre, Jacinto, Boscato, Cenci, & Pereira-Cenci, 2014). One disadvantage of using intra-radicular posts is healthier tooth structure removal for root canal post fitting (Lazari et al., 2013). Moreover, post-placement procedures negatively affect the behavior of the restored teeth biomechanically (Roscoe, Noritomi, Novais, & Soares, 2013). Alternatively, in 1999, the term "endocrown" has been suggested by Bindl and Mormann, to designate a monoblock ceramic crown bonded to depulped posterior teeth (Belleflamme et al., 2017). This type of restorations assembling the post, core-crown complex in one component (Otto, 2004; Zarone et al., 2006), which can adhere to the chamber of the pulp internally and on the margins of preparation externally, thereby pulpal walls and adhesive cementation can be resulting in mechanical retention at both micro and macro levels (G. R. Biacchi, B. Mello, & R. T. Basting, 2013). A minimally invasive approach of endocrown performed efficiently and mainly can lower post placement failures' rate (Belleflamme et al., 2017). Removing less amount of healthy tooth structure compared to other techniques, inferior chair time required, and the masticatory stresses at the surface of the tooth with restoration borders are more dissolute adequately along with the restored tooth structure (A. Bindl & Mormann, 1999). Root canal-treated premolars teeth (RCTPT) have specific challenges due to their more brittle behavior than vital teeth, their tissue faults that happened throughout the preparations, and the risk of accidental root perforation during preparing a post space (C. L. Lin, Chang, & Pai, 2011). Furthermore, the anatomy form, the critical crown/root ratio, and being under forces as shear and/or compressive made cusps fractures more prone to happen in premolars (Mergulhão, de Mendonça, de Albuquerque, & Braz, 2019). Since premolar teeth had less pulp chamber for mechanical retention and unequal proportion ratio of tooth structure had been prepared to the overall crown, causing a higher failure rate in endocrown for premolars than molars (A. Bindl, Richter, & Mormann, 2005). The non-silica ceramics reinforced with alumina or spinel and ceramics with silica-based feldspar were initial materials for endocrown manufacturing (A. Bindl & Mormann, 1999), using either a pressed technique or

recently computerized designing and manufacturing technology called CAD/CAM system. In the last decade, glass-ceramics can be surface modified either by air-abrasion or hydrofluoric acid is considered as the material of choice; therefore, their adhesion to the tooth structure is improved. Endocrown can be fabricate with glass ceramics reinforced either with leucite or lithium disilicate, since they revealed flexural strength higher than other materials like composite or feldspathic glass ceramics, and presented well resistance to the masticatory occlusal forces (Biacchi & Basting, 2012; A. Bindl et al., 2005; Otto, 2004; J. Zhu, Rong, Wang, & Gao, 2017), the material used may have also an effect on the endocrowns performing (H. M. El-Damanhoury, R. N. Haj-Ali, & J. A. Platt, 2015). Even with the popularity of the endocrown restorations, clinicians still wonder about using endocrowns on severely destructed premolars teeth as an alternative to the conventional treatments with intraradicular posts. Actually, regarding to uppermost our expertise, literature remain have shortness in its available clinical evidence, and the existing ones had short-term follow-up, for example averaged from six to thirty six months (A. Bindl & Mormann, 1999; Decerle et al., 2014; Roscoe et al., 2013). Nevertheless, endocrowns fracture strength is well evaluated in in-vitro studies and reasonably available (G. R. Biacchi et al., 2013; Ramírez-Sebastià et al., 2014).

Changes occurring in root canal treated teeth:

Lower stiffness and fracture resistance of RCTT mainly are decays, trauma, and extensive tooth preparation, in addition to the dehydration or physical changes in dentin affecting the structural integrity (Chang, Kuo, Lin, & Chang, 2009). The teeth had to be restored with a solid base, structural strength, and high integrity depend on the quality of the remaining tooth structure of the restored tooth (Assif, Nissan, Gafni, & Gordon, 2003; C.-L. Lin & Pai, 2010). Root canal access compromises the dental hard tissue integrity, leading to a higher incidence of functional cusp deflection and increased fracture occurrence rate (Mannocci, Qualtrough, Worthington, Watson, & Pitt Ford, 2005). The ample structure loss may deteriorate the condition when root canal treatment is combined with mesial-occlusal-distal preparation cavity, especially in premolar teeth. The premolars went through root canal treatment had a prognosis dependent on different variables, such as the volume of tooth structure loss (Bitter et al., 2009), the cavity preparation design and depth (Bitter et al., 2009; Liu, Fok, & Li, 2014), presence of 1.5-2 mm ferrule preparation height minimally (Samran, El Bahra, & Kern, 2013), and restoration material used (H. M. El-Damanhoury et al., 2015). In addition, loss of pulpal tissue leads to the feedback deficiency of the neurosensory system, which may have been recorded as lowering the defense mechanism of the RCTT during mastication (Robbins, 2002). In normal human teeth which were extracted, Mustafa et al. 2020 mention in their study that the effect of endodontic treatment on the occlusal loading leads to a reduction in stiffness of tooth structure by about 5% due to loss of occlusal strength, while preparations on occlusal surfaces and mesial-occlusal-distal dental preparations decrease the strength by 20%, and 63%, respectively (Mustafa et al., 2020). A study also confirmed this reduction carried out by Oliveira et al. in endodontically treated premolar teeth (Denehy & Boyer, 1987).

Restoration available for root canal treated premolars teeth (RCTPT):

Although there are several studies on RCTPT, dental material choices and treatment planning are still controversial, especially for severely destructed premolars teeth. Therefore, restoring functional demand and coronal tooth structure remains are parts of the criteria that must be considered during the treatment plan (Faria, Rodrigues, de Almeida Antunes, de Mattos, & Ribeiro, 2011).

Missing less than half of coronal RCTPT structure:

Enough coronal tooth structure can provide resistance, retention, and restoration strength. Hence, premolars teeth that require root canal therapy with existing medium-sized restorations do not need a post-core restoration; instead, an endocrown or onlay restorations are suggested as complete coronal coverage, using a composite resin liner base (Dietschi & Spreafico, 1998) to block out the undercuts and to produce a smooth preparation design (D. Dietschi et al., 2008; Reeh, Messer, & Douglas, 1989).

Missing up to two-thirds of the coronal RCTPT structure:

Missing acquired surface and proper tooth structure for adhesion mandated the suggestion of using endocrown or restoration of post and core to strengthen dental-restoration complex and increase fracture resistance (Bitter & Kielbassa, 2007; C.-L. Lin & Pai, 2010). The proper preparation design and the remaining coronal dental tissue must introduce the resistance to functional and shear forces. The butt margin or ferrule preparation in endocrown should be achieved to guarantee both success and survivability of the restoration depending on the upper limit of tooth structure conservation (Bitter & Kielbassa, 2007; Sevimli et al., 2015). Available literature and scientific data suggested the adhesive techniques for post and core placement (D. Dietschi et al., 2008). However, this option correlated to the amount of tooth structure may possess a higher failure rate biomechanically (Lander & Dietschi, 2008). Since the RCTPT is more prone to fracture after restoration (Salis, Hood, Stokes, & Kirk, 1987), endocrown restoration is thought to present a satisfactory clinical alternative (Tzimas, Tsiafita, Gerasimou, & Tsitrou, 2018).

Missing most of the coronal RCTPT structure:

This situation in the long term presents the more challenging problems biomechanically and cannot be approached. Unless a minimum of two-millimeter circumferential dentin collar in height present (Pereira, de Ornelas, Conti, & do Valle, 2006), a ferrule effect can be attained by performing orthodontic extrusion and or extensive crown lengthening procedures to ensure restoration retention and resistance (de Oliveira et al., 2015; Meng, Ma, Wang, & Chen, 2018; Parwani & Parwani, 2014). Failure to restore severely compromised posterior teeth can mandate the extraction and dental implants as an alternative to conventional treatment (Cho, 2004; Mordohai, Reshad, & Jivraj, 2005).

Endocrown restorations:

Tillnow, the exact definition of the endocrown is unclear. In 1999 endocrown was defined by Bindl et al. as "circular preparation with equigingival butt margin and a central retention cavity of the entire pulp chamber" (Andreas Bindl & Mörmann, 1999). In addition, other definitions also are suggested like "a total porcelain crown fixed to depulped posterior tooth secured with the pulp chamber internally and adhere to the cavity margins" (Gislaine Rosa Biacchi, Beatriz Mello, & Roberta Tarkany Basting, 2013), while for Bernhart et al. (Bernhart, Bräuningb, Altenburgerc, & Wrbasd, 2010), "a tooth prepared with a height reduction of only 2 mm is considered as an endocrown if the tooth is nonvital and there is at least a 2 mm of height retention in the pulp chamber". However, the quantity of residual tooth structure, the preparation of peripheral butt finishing margins, or the custom cavity of the pulp chamber used as macro-mechanical retention, and micro-retention would be properly obtained using adhesive cement are variables that could affect on retention and implementation of restorations. Conservation of maximum tissue, preparations with minimum invasiveness for restoring RCTPT are now measured as the gold standard (Didier Dietschi, Olivier Duc, Ivo Krejci, & Avishai Sadan, 2008). Dependent on this philosophy, endocrowns suggested as a prosthetic choice to restore root canal-treated premolars teeth (C. L. Lin et al., 2011) with excessive tissue loss. Fracture of the onlay, decay, debonding (loss of retention) are the most prevalent failures causes of ceramic endocrown, while other causes, for example, complications in periodontal and root canal treatment, and maybe the loss of the tooth restored can make the same failures (Abduo & Sambrook, 2018). In comparing the endocrown performance on premolars and molars, failures in premolars that perceived endocrown revealed a higher percent than molars due to their adhesive failure (A. Bindl et al., 2005). Premolar adhesion failure endocrowns might be functional because of the exposure to both shear and compressive forces (Shafiei, Tavangar, Ghahramani, & Fattah, 2014), less adhesive surface bonding in comparison to molars, less pulp chamber for mechanical retention, and the amount of the tooth structure that had prepared are higher than that of the entire dental coronal part causing premolars to have higher leverage than molars (Sevimli et al., 2015). Endocrown approach is indicated mainly when there is an extreme dental coronal loss; restricted interproximal distance and conventional restoration with post and core with crown construction is impossible due to an insufficient ceramic thickness (Chang et al., 2009). Endocrowns had benefits in the way of application, less preparation and working time, optical properties, and fewer prices compared to conventional methods (Didier Dietschi et al., 2008; Singh, Abrol, Agarwal, & Madan, 2019).

Rules in endocrown restorations (generally):

The core retention of 2 mm centrally is recommended to allow the optimum resistance and retention forms (Hatem M El-Damanhoury, Reem N Haj-Ali, & Jeffrey A Platt, 2015; P. Magne et al., 2014). In addition, other parameters for endocrown preparation are suggested to include:

1. 2 to 3 mm reduction of the cusps;
2. Internal tapers of the pulp chamber occluso-cervical 6-8 degrees;
3. Flat pulpal floor or saddle-like anatomy of the cavity floor;
4. Supragingival enamel margins when possible;
5. 90° butt margins; and
6. Smooth internal transitions;(Elagra, 2019; Sevimli et al., 2015; Singh, Abrol, Agarwal, & Madan)

Increasing fracture resistance due to incorporating ferrule effect with preparations was well investigated (Forberger & Gohring, 2008; Pereira et al., 2006; Samran et al., 2013). In addition, the ferrule effect has been established to enhance significant fracture resistance in comparison to the existence of a post alone(Lima, Spazzin, Galafassi, Correr-Sobrinho, & Carlini-Júnior, 2010), while the supplement of preparations with ferrule features to the endocrown with slight chamfer preparation is recommended(Beuer, Aggstaller, Edelhoff, & Gernet, 2008). However, there is a deficiency in the literature data on the ferrule effect of endocrown preparation on premolars teeth.

Rules of endocrowns on root canal treated premolars teeth (RCTPT):

The endocrown preparation on premolars teeth consists of 2 mm height reduction, may require but not always a preparation with 1-1.2 mm butt joint margin, as much as possible supragingival cervical margins, walls divergence 6–8 degree in occlusal direction is required, and 4-5 mm intraradicular extension for the pulp chamber and the endodontic root canals to be unceasing made core-crown complex as a single monoblock unit restoration structure (A. Bindl et al., 2005; Lise et al., 2017; Sevimli et al., 2015). The endocrowns occlusal ceramic portion thickness is usually 3-7 mm(Elagra, 2019). In 1998 Mörmann revealed in his study that fracture resistance of ceramic crowns has positive proportions with its thicknesses, and the fracture resistance of 5.5 mm endocrowns was two times of crowns made by ceramics with 1.5 mm occlusal thickness (Mörmann, Bindl, Lüthy, & Rathke, 1998; Tsai, Petsche, Anusavice, & Yang, 1998).

Technique for endocrown preparation design:

Occlusal preparation:

Mainly occlusal preparation aims to achieve a total occlusal height reduction surface axially of at least 2 mm. Occlusal height can be reduced by providing two millimeter deep grooves as guides, next reducing the occlusal surface using a diamond wheel bur to connect the grooves with each other's, by direct the bur with the tooth long axis and parallel to the occlusal plane. Supragingival margins should be retained as possible; friable enamel with thickness minor than 2 mm should be removed to achieve the ideal condition (Andreas Bindl & Mörmann, 1999). The thickness of material for cusp coverage has to be ≥ 1 to 1.5 mm(Pascal Magne, Schlichting, Maia, & Baratieri, 2010; G. T. Rocca, Rizcalla, Krejci, & Dietschi, 2015) for composite and lithium disilicate (pressed or CAD/CAM) and ≥ 2 to 2.5 mm for feldspathic ceramic and leucite-reinforced glass-ceramic(Veneziani, 2017).

Axial preparation:

Any undercuts in the cavity preparation should be removed in this step. A round 7 degree tapered diamond bur is used to make a continuous pulp chamber with endodontic root canals. A cylindrical swivel with a 5 mm intraradicular extension for the premolars is recommended with polishing the total cervical bar to eliminate micro-irregularities and create a polished flat surface(Elagra, 2019). The mechanical properties will enhance with more extension in the pulp chamber (Dartora et al., 2018). Many studies stated that premolar endocrown required more intra-radicular extension to improve the success of restoration (Elagra, 2019; Gaintantzopoulou & El-Damanhoury, 2016). Gulec and Ulusoy 2017 evaluated two designs of endocrowns on maxillary first premolar without and with 3 mm intraradicular extension; they found that remaining tooth structures were well protected with the altered design

endocrown that had extensions inside the canals than the unmodified endocrown design (Gulec & Ulusoy, 2017).

Ferrule or no ferrule feature:

The ferrule effect in post-core and crown complex was exhaustively studied and well approved to increase fracture resistance and fatigue failure (Forberger & Gohring, 2008; Ma, Nicholls, Junge, & Phillips, 2009; Pereira et al., 2006). A study by Einhorn et al. 2019 evaluated the effect of presence ferrule preparation with fracture resistance of mandibular molar endocrowns, concluded that failure loads on endocrown preparations with ferrule design showed a significantly higher amount than conventional restorations of endocrown, while based on bonding surface adhesion area, failure stress revealed no difference among the groups, and the endocrown preparations containing ferrule design with 1mm revealed more minor occurrences of disastrous failure (Einhorn, DuVall, Wajdowicz, Brewster, & Roberts, 2019). Endocrown inner surface fitness seemed to be reduced, with the addition of ferrule design make preparation more complex (Elagra, 2019). There is a lack of data in the literature about the ferrule effect on premolars teeth.

Restorative and cementation materials available:

Endocrown restoration can be construction with various materials, mainly by ceramics and composite, either pressed or blocks with a computerized designing and manufacturing system (CAD-CAM technology) (Forberger & Gohring, 2008; Giovanni Tommaso Rocca et al., 2016; Sedrez-Porto, Rosa, da Silva, Munchow, & Pereira-Cenci, 2016). The most used ceramic materials for endocrown restoration fabrication are leucite glass-ceramic, lithium disilicate, alumina silicate, zirconia, , and feldspathic (Aktas, Yerlikaya, & Akca, 2018; Gresnigt, Ozcan, van den Houten, Schipper, & Cune, 2016; Lise et al., 2017; Giovanni Tommaso Rocca et al., 2016). Lithium disilicate and leucite reinforced ceramics had the ability to acid-etched and had high mechanical strength, which enabled them, associated with adhesive systems, to make the posterior teeth restoration is possible without using post and cores technique (Veselinović, Todorović, Lisjak, & Lazić, 2008). Ceramic restorations can be pressed or milled CAD/CAM systems in the laboratory by processing the feldspathic ceramic blocks (Jedynakiewicz & Martin, 2001). IPS Empress, which is a leucite-reinforced glass-ceramic, had an excellent marginal adaptation; however, the material strength restricts its usage on an anterior segment like a single unit full-coverage restorations, while onlays or partial veneer crowns can be used in the posterior segment (Brochu & El-Mowafy, 2002; Fradeani & Redemagni, 2002; Murgueitio & Bernal, 2012). IPS e.max lithium disilicate, a glass-ceramic, possesses high flexural strength, high fracture toughness, and high thermal shock resistance because of low thermal expansion (Tysowsky, 2009). IPS e.max, whether pressed or milled, is commonly used for veneers, inlays, onlays, partial coverage, and full coverage crowns (Giordano, 2006). Furthermore, the majority of composite materials used are nano-ceramics and hybrid ceramic-polymer infiltrated (H. M. El-Damhoury et al., 2015; Ramirez-Sebastia, Bortolotto, Roig, & Krejci, 2013; G. T. Rocca, Rizcalla, & Krejci, 2013). Laboratory systems such as indirect composite and porcelain systems are recently available as one of the restoration options; showed well optical properties, wear resistance, lower polymerization shrinkage, and excellent marginal and proximal fit (Ferrari, Vichi, Mannocci, & Mason, 2000). Dental cement aims to retain restorations on prepared teeth and help seal the micro gap between the restoration and tooth. To date, resin cement has superior mechanical and aesthetic properties, used in the cementation of indirect composite restorations, metal, and ceramics (McCabe & Walls, 2013). Luting resins (both light and dual-polymerization activation reaction) are available and can be set adequately when used as a luting cement for bulk endocrown restorations (Gregor et al., 2014). Usually, root canal sealers contain eugenol in their composition are believed to inhibit the resin cement polymerization reaction (Sevimli et al., 2015); So, thorough root canal walls irrigation and acid etching is mandatory.

Conclusion:

Endocrowns can be used as another option than traditional post-core for restoring root canal treated premolars teeth (RCTPT) with severely destructive dental tissue. Mechanical and optical properties, less working and chair time consuming, and prices made endocrown preferable over traditional methods. However, further in vitro studies are required to be accomplished, assessing the endocrown preparation and its alternative features to improve the durability and retention of the restoration in premolars teeth.

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References

- [1] Abduo, J., & Sambrook, R. J. (2018). Longevity of ceramic onlays: A systematic review. *Journal of Esthetic and Restorative Dentistry*, 30(3), 193-215.
- [2] Aktas, G., Yerlikaya, H., & Akca, K. (2018). Mechanical Failure of Endocrowns Manufactured with Different Ceramic Materials: An In Vitro Biomechanical Study. *Journal of prosthodontics*, 27(4), 340-346.
- [3] Assif, D., Nissan, J., Gafni, Y., & Gordon, M. (2003). Assessment of the resistance to fracture of endodontically treated molars restored with amalgam. *The Journal of prosthetic dentistry*, 89(5), 462-465.
- [4] Belleflamme, M. M., Geerts, S. O., Louwette, M. M., Grenade, C. F., Vanheusden, A. J., & Mainjot, A. K. (2017). No post-no core approach to restore severely damaged posterior teeth: An up to 10-year retrospective study of documented endocrown cases. *Journal of Dentistry*, 63, 1-7.
- [5] Bernharta, J., Bräuningb, A., Altenburgerc, M., & Wrbasd, K. (2010). Cerec® 3D Endocrowns–Two-year Clinical Examination of CAD/CAM Crowns for Restoring Endodontically Treated Molars Cerec® 3D-Endokronen–Untersuchung der klinischen Bewährung von CAD/CAM-Kronen. *International journal of computerized dentistry*, 13, 141-154.
- [6] Beuer, F., Aggstaller, H., Edelhoff, D., & Gernet, W. (2008). Effect of preparation design on the fracture resistance of zirconia crown copings. *Dental materials journal*, 27(3), 362-367.
- [7] Biacchi, G. R., & Basting, R. T. (2012). Comparison of fracture strength of endocrowns and glass fiber post-retained conventional crowns. *Operative dentistry*, 37(2), 130-136.
- [8] Biacchi, G. R., Mello, B., & Basting, R. T. (2013). The endocrown: an alternative approach for restoring extensively damaged molars. *Journal of Esthetic and Restorative Dentistry*, 25(6), 383-390.
- [9] Bindl, A., & Mormann, W. H. (1999). Clinical evaluation of adhesively placed Cerec endo-crowns after 2 years--preliminary results. *Journal of Adhesive Dentistry*, 1(3), 255-265.
- [10] Bindl, A., Richter, B., & Mormann, W. H. (2005). Survival of ceramic computer-aided design/manufacturing crowns bonded to preparations with reduced macroretention geometry. *International Journal of Prosthodontics*, 18(3), 219-224.
- [11] Bitter, K., & Kielbassa, A. M. (2007). Post-endodontic restorations with adhesively luted fiber-reinforced composite post systems: a review. *American journal of dentistry*, 20(6), 353-360.
- [12] Bitter, K., Noetzel, J., Stamm, O., Vaudt, J., Meyer-Lueckel, H., Neumann, K., & Kielbassa, A. M. (2009). Randomized clinical trial comparing the effects of post placement on failure rate of postendodontic restorations: preliminary results of a mean period of 32 months. *Journal of endodontics*, 35(11), 1477-1482.
- [13] Brochu, J.-F., & El-Mowafy, O. (2002). Longevity and clinical performance of IPS-Empress ceramic restorations-a literature review. *Journal-Canadian Dental Association*, 68(4), 233-238.
- [14] Chang, C.-Y., Kuo, J.-S., Lin, Y.-S., & Chang, Y.-H. (2009). Fracture resistance and failure modes of CEREC endo-crowns and conventional post and core-supported CEREC crowns. *Journal of Dental Sciences*, 4(3), 110-117.
- [15] Cho, G. C. (2004). Evidence-based approach for treatment planning options for the extensively damaged dentition. *Journal of the California Dental Association*, 32(12), 983-990.
- [16] Dartora, N. R., de Conto Ferreira, M. B., Moris, I. C. M., Brazao, E. H., Spazin, A. O., Sousa-Neto, M. D., . . . Gomes, E. A. (2018). Effect of Intracoronal Depth of Teeth Restored with Endocrowns on Fracture Resistance: In Vitro and 3-dimensional Finite Element Analysis. *Journal of endodontics*, 44(7), 1179-1185.
- [17] de Oliveira, P. S., Chiarelli, F., Rodrigues, J. A., Shibli, J. A., Zizzari, V. L., Piattelli, A., . . . Perrotti, V. (2015). Aesthetic Surgical Crown Lengthening Procedure. *Case reports in dentistry*, 2015, 437412.
- [18] Decerle, N., Bessadet, M., Munoz-Sanchez, M. L., Eschevins, C., Veyrune, J., & Nicolas, E. (2014). Evaluation of Cerec endocrowns: a preliminary cohort study. *The European journal of prosthodontics and restorative dentistry*, 22(2), 89-95.
- [19] Denehy, G., & Boyer, D. (1987). Fracture resistance of endodontically prepared teeth using various restorative

- materials. *Journal of the American Dental Association* (1939), 115(1), 57-60.
- [20] Dietschi, D., Duc, O., Krejci, I., & Sadan, A. (2008). Biomechanical considerations for the restoration of endodontically treated teeth: a systematic review of the literature, Part II (Evaluation of fatigue behavior, interfaces, and in vivo studies). *Quintessence international*, 39(2).
- [21] Dietschi, D., & Spreafico, R. (1998). Current clinical concepts for adhesive cementation of tooth-colored posterior restorations. *Practical periodontics and aesthetic dentistry: PPAD*, 10(1), 47-54; quiz 56.
- [22] Einhorn, M., DuVall, N., Wajdowicz, M., Brewster, J., & Roberts, H. (2019). Preparation Ferrule Design Effect on Endocrown Failure Resistance. *Journal of prosthodontics*, 28(1), e237-e242.
- [23] El-Damanhoury, H. M., Haj-Ali, R. N., & Platt, J. A. (2015). Fracture resistance and microleakage of endocrowns utilizing three CAD-CAM blocks. *Operative dentistry*, 40(2), 201-210.
- [24] Elagra, M. (2019). Endocrown preparation. *International journal of applied dental sciences*, 5, 253-256.
- [25] Faria, A. C. L., Rodrigues, R. C. S., de Almeida Antunes, R. P., de Mattos, M. d. G. C., & Ribeiro, R. F. (2011). Endodontically treated teeth: characteristics and considerations to restore them. *Journal of prosthodontic research*, 55(2), 69-74.
- [26] Ferrari, M., Vichi, A., Mannocci, F., & Mason, P. N. (2000). Retrospective study of the clinical performance of fiber posts. *American journal of dentistry*, 13(Spec No), 9B-13B.
- [27] Forberger, N., & Gohring, T. N. (2008). 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. *The Journal of prosthetic dentistry*, 100(4), 264-273.
- [28] Fradeani, M., & Redemagni, M. (2002). An 11-year clinical evaluation of leucite-reinforced glass-ceramic crowns: a retrospective study. *Quintessence International*, 33(7), 503-510.
- [29] Gaintantzopoulou, M. D., & El-Damanhoury, H. M. (2016). Effect of Preparation Depth on the Marginal and Internal Adaptation of Computer-aided Design/Computer-assisted Manufacture Endocrowns. *Operative dentistry*, 41(6), 607-616.
- [30] Giordano, R. (2006). Materials for chairside CAD/CAM-produced restorations. *The Journal of the American Dental Association*, 137, 14S-21S.
- [31] Gregor, L., Bouillaguet, S., Onisor, I., Ardu, S., Krejci, I., & Rocca, G. T. (2014). Microhardness of light-and dual-polymerizable luting resins polymerized through 7.5-mm-thick endocrowns. *The Journal of prosthetic dentistry*, 112(4), 942-948.
- [32] Gresnigt, M. M., Ozcan, M., van den Houten, M. L., Schipper, L., & Cune, M. S. (2016). Fracture strength, failure type and Weibull characteristics of lithium disilicate and multiphase resin composite endocrowns under axial and lateral forces. *Dental Materials*, 32(5), 607-614.
- [33] Gulec, L., & Ulusoy, N. (2017). Effect of Endocrown Restorations with Different CAD/CAM Materials: 3D Finite Element and Weibull Analyses. *Biomed Res Int*, 2017, 5638683. doi:10.1155/2017/5638683
- [34] Jedynekiewicz, N. M., & Martin, N. (2001). CEREC: science, research, and clinical application. *Compendium of continuing education in dentistry*, 22(6 Suppl), 7-13.
- [35] Lander, E., & Dietschi, D. (2008). Endocrowns: a clinical report. *Quintessence International*, 39(2), 99-106.
- [36] Lazari, P. C., Oliveira, R. C., Anchieta, R. B., Almeida, E. O., Freitas Junior, A. C., Kina, S., & Rocha, E. P. (2013). Stress distribution on dentin-cement-post interface varying root canal and glass fiber post diameters. A three-dimensional finite element analysis based on micro-CT data. *Journal of Applied Oral Science*, 21(6), 511-517.
- [37] Lima, A. F. d., Spazzin, A. O., Galafassi, D., Correr-Sobrinho, L., & Carlini-Júnior, B. (2010). Influence of ferrule preparation with or without glass fiber post on fracture resistance of endodontically treated teeth. *Journal of Applied Oral Science*, 18(4), 360-363.
- [38] Lin, C.-L., & Pai, C. A. (2010). Numerical investigation of failure risk of cad/cam ceramic restoration for an endodontically treated maxillary premolar with no preparation. *Biomedical Engineering: Applications, Basis and Communications*, 22(04), 327-335.
- [39] Lin, C. L., Chang, Y. H., & Pai, C. A. (2011). Evaluation of failure risks in ceramic restorations for endodontically treated premolar with MOD preparation. *Dental Materials*, 27(5), 431-438.
- [40] Lise, D. P., Van Ende, A., De Munck, J., Suzuki, T. Y. U., Vieira, L. C. C., & Van Meerbeek, B. (2017). Biomechanical behavior of endodontically treated premolars using different preparation designs and CAD/CAM materials. *Journal of Dentistry*, 59, 54-61.

- [41] Liu, X., Fok, A., & Li, H. (2014). Influence of restorative material and proximal cavity design on the fracture resistance of MOD inlay restoration. *Dental Materials*, 30(3), 327-333.
- [42] Ma, P. S., Nicholls, J. I., Junge, T., & Phillips, K. M. (2009). Load fatigue of teeth with different ferrule lengths, restored with fiber posts, composite resin cores, and all-ceramic crowns. *The Journal of prosthetic dentistry*, 102(4), 229-234.
- [43] Magne, P., Carvalho, A. O., Bruzi, G., Anderson, R. E., Maia, H. P., & Giannini, M. (2014). Influence of no-ferrule and no-post buildup design on the fatigue resistance of endodontically treated molars restored with resin nanoceramic CAD/CAM crowns. *Operative dentistry*, 39(6), 595-602.
- [44] Magne, P., Schlichting, L. H., Maia, H. P., & Baratieri, L. N. (2010). In vitro fatigue resistance of CAD/CAM composite resin and ceramic posterior occlusal veneers. *The Journal of prosthetic dentistry*, 104(3), 149-157.
- [45] Mannocci, F., Qualtrough, A. J., Worthington, H. V., Watson, T. F., & Pitt Ford, T. R. (2005). Randomized clinical comparison of endodontically treated teeth restored with amalgam or with fiber posts and resin composite: five-year results. *Operative dentistry*, 30(1), 9-15.
- [46] McCabe, J. F., & Walls, A. W. (2013). *Applied dental materials*: John Wiley & Sons.
- [47] Meng, Q., Ma, Q., Wang, T., & Chen, Y. (2018). An in vitro study evaluating the effect of ferrule design on the fracture resistance of endodontically treated mandibular premolars after simulated crown lengthening or forced eruption methods. *BioMed Central oral health*, 18(1), 83.
- [48] Mergulhão, V., de Mendonça, L., de Albuquerque, M., & Braz, R. (2019). Fracture resistance of endodontically treated maxillary premolars restored with different methods. *Operative dentistry*, 44(1), E1-E11.
- [49] Mordohai, N., Reshad, M., & Jivraj, S. A. (2005). To extract or not to extract? Factors that affect individual tooth prognosis. *Journal of the California Dental Association*, 33(4), 319-328.
- [50] Mörmann, W. H., Bindl, A., Lüthy, H., & Rathke, A. (1998). Effects of preparation and luting system on all-ceramic computer-generated crowns. *International Journal of Prosthodontics*, 11(4).
- [51] Murgueitio, R., & Bernal, G. (2012). Three-year clinical follow-up of posterior teeth restored with leucite-reinforced ips empress onlays and partial veneer crowns. *Journal of prosthodontics*, 21(5), 340-345.
- [52] Mustafa, M., AlJeaidei, Z. A., AlQahtani, A. R., Abuelqomsan, M. A. S., Alofi, R. S., Alghomlas, Z. I., & Abdullah AlOthman, T. (2020). Comparative Analysis of Fracture Strength of Remaining Tooth Structure after Endodontic Treatment with Various Access Cavity Preparation Techniques. *The Open Dentistry Journal*, 14(1).
- [53] Otto, T. (2004). Computer-aided direct all-ceramic crowns: preliminary 1-year results of a prospective clinical study. *International Journal of Periodontics & Restorative Dentistry*, 24(5), 446-455.
- [54] Parwani, S. R., & Parwani, R. N. (2014). Surgical crown lengthening: a periodontal and restorative interdisciplinary approach. *General dentistry*, 62(6), e15-19.
- [55] Pereira, J. R., de Ornelas, F., Conti, P. C., & do Valle, A. L. (2006). Effect of a crown ferrule on the fracture resistance of endodontically treated teeth restored with prefabricated posts. *The Journal of prosthetic dentistry*, 95(1), 50-54.
- [56] Ramírez-Sebastià, A., Bortolotto, T., Cattani-Lorente, M., Giner, L., Roig, M., & Krejci, I. (2014). Adhesive restoration of anterior endodontically treated teeth: influence of post length on fracture strength. *Clinical oral investigations*, 18(2), 545-554.
- [57] Ramirez-Sebastia, A., Bortolotto, T., Roig, M., & Krejci, I. (2013). Composite vs ceramic computer-aided design/computer-assisted manufacturing crowns in endodontically treated teeth: analysis of marginal adaptation. *Operative dentistry*, 38(6), 663-673.
- [58] Reeh, E. S., Messer, H. H., & Douglas, W. H. (1989). Reduction in tooth stiffness as a result of endodontic and restorative procedures. *Journal of endodontics*, 15(11), 512-516.
- [59] Robbins, J. W. (2002). Restoration of the endodontically treated tooth. *Dental Clinics of North America*, 46(2), 367-384.
- [60] Rocca, G. T., Rizcalla, N., & Krejci, I. (2013). Fiber-reinforced resin coating for endocrown preparations: a technical report. *Operative dentistry*, 38(3), 242-248.
- [61] Rocca, G. T., Rizcalla, N., Krejci, I., & Dietschi, D. (2015). Evidence-based concepts and procedures for bonded inlays and onlays. Part II. Guidelines for cavity preparation and restoration fabrication. *The international journal of esthetic dentistry*, 10(3), 392-413.

- [62] Rocca, G. T., Sedlakova, P., Saratti, C. M., Sedlacek, R., Gregor, L., Rizcalla, N., . . . Krejci, I. (2016). Fatigue behavior of resin-modified monolithic CAD–CAM RNC crowns and endocrowns. *Dental Materials*, 32(12), e338-e350.
- [63] Roscoe, M. G., Noritomi, P. Y., Novais, V. R., & Soares, C. J. (2013). Influence of alveolar bone loss, post type, and ferrule presence on the biomechanical behavior of endodontically treated maxillary canines: strain measurement and stress distribution. *The Journal of prosthetic dentistry*, 110(2), 116-126.
- [64] Salis, S. G., Hood, J. A., Stokes, A. N., & Kirk, E. E. (1987). Patterns of indirect fracture in intact and restored human premolar teeth. *Endodontics & dental traumatology*, 3(1), 10-14.
- [65] Samran, A., El Bahra, S., & Kern, M. (2013). The influence of substance loss and ferrule height on the fracture resistance of endodontically treated premolars. An in vitro study. *Dental Materials*, 29(12), 1280-1286.
- [66] Sarkis-Onofre, R., Jacinto, R. C., Boscatto, N., Cenci, M. S., & Pereira-Cenci, T. (2014). Cast metal vs. glass fibre posts: a randomized controlled trial with up to 3 years of follow up. *Journal of Dentistry*, 42(5), 582-587.
- [67] Sedrez-Porto, J. A., Rosa, W. L., da Silva, A. F., Munchow, E. A., & Pereira-Cenci, T. (2016). Endocrown restorations: A systematic review and meta-analysis. *Journal of Dentistry*, 52, 8-14. doi:10.1016/j.jdent.2016.07.005
- [68] Sevimli, G., Cengiz, S., & Oruc, M. S. (2015). Endocrowns: review. *Journal of Istanbul University Faculty of Dentistry*, 49(2), 57-63.
- [69] Shafiei, F., Tavangar, M. S., Ghahramani, Y., & Fattah, Z. (2014). Fracture resistance of endodontically treated maxillary premolars restored by silorane-based composite with or without fiber or nano-ionomer. *The journal of advanced prosthodontics*, 6(3), 200.
- [70] Singh, A., Abrol, K., Agarwal, S., & Madan, R. (2019). Endocrown Restorations: A Review. *Chronicles of Dental Research*, 8(2), 21-26.
- [71] Tsai, Y. L., Petsche, P. E., Anusavice, K. J., & Yang, M. C. (1998). Influence of glass-ceramic thickness on Hertzian and bulk fracture mechanisms. *International Journal of Prosthodontics*, 11(1), 27-32.
- [72] Tysowsky, G. W. (2009). The science behind lithium disilicate: a metal-free alternative. *Dent Today*, 28(3), 112-113.
- [73] Tzimas, K., Tsiafitsa, M., Gerasimou, P., & Tsitrou, E. (2018). Endocrown restorations for extensively damaged posterior teeth: clinical performance of three cases. *Restorative dentistry & endodontics*, 43(4), e38.
- [74] Veneziani, M. (2017). Posterior indirect adhesive restorations: updated indications and the Morphology Driven Preparation Technique. *The international journal of esthetic dentistry*, 12(2), 204-230.
- [75] Veselinović, V., Todorović, A., Lisjak, D., & Lazić, V. (2008). Restoring endodontically treated teeth with all-ceramic endo-crowns: case report. *Stomatološki glasnik Srbije*, 55(1), 54-64.
- [76] Zarone, F., Sorrentino, R., Apicella, D., Valentino, B., Ferrari, M., Aversa, R., & Apicella, A. (2006). Evaluation of the biomechanical behavior of maxillary central incisors restored by means of endocrowns compared to a natural tooth: a 3D static linear finite elements analysis. *Dental Materials*, 22(11), 1035-1044.
- [77] Zhu, J., Rong, Q., Wang, X., & Gao, X. (2017). Influence of remaining tooth structure and restorative material type on stress distribution in endodontically treated maxillary premolars: A finite element analysis. *The Journal of prosthetic dentistry*, 117(5), 646-655.
- [78] Zhu, Z., Dong, X. Y., He, S., Pan, X., & Tang, L. (2015). Effect of Post Placement on the Restoration of Endodontically Treated Teeth: A Systematic Review. *International Journal of Prosthodontics*, 28(5), 475-483.