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Restoration of the endodontically treated tooth

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The restoration of the endodontically treated tooth is a subject that has been evaluated and discussed widely in the dental literature. Despite the large number of in-vitro and in-vivo investigations, however, there is still much confusion regarding ideal treatment. Scurria et al. [1] followed up the restorative outcome of 1199 endodontically treated teeth through an insurance claims system. They reported the percentage of noncrown restorations placed during the subsequent 2 years after endodontic therapy: the anterior tooth group was 67%, the premolar group was 54%, and the molar group was 50%. Based on these data, it seems clear that there continues to be significant confusion regarding the restoration of endodontically treated teeth.

The endodontically treated tooth is a unique subset of teeth requiring restoration because of several factors. First, it was thought that the dentin of endodontically treated teeth was significantly different than vital dentin [2,3]. However, more current research casts doubt on this assumption [4,5]. Second, a percentage of structural integrity is lost because of the access preparation [6]. This loss clearly has a negative effect on the fracture resistance of the endodontically treated tooth. Third, the neurosensory feedback mechanism is impaired with the removal of the pulpal tissue, which may result in decreased protection of the endodontically treated tooth during mastication [7].

The longevity of endodontically treated teeth is difficult to evaluate because of the many mitigating factors. Perhaps the most important factor that is not reported in clinical studies is the amount of remaining coronal tooth structure before the final restoration. This factor is much

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more important than others that are reported, such as post material and design and cement and core material. Mentink et al. [8] reported an 82% success rate in post-restored teeth after 10 years. Torbjorner et al. [9] reported a 2.1% failure rate per year. Finally, Nanayakkara et al. [10] reported the median survival rate to be 17.4 years. The failure of endodontically treated teeth is seldom caused by the endodontic therapy. The primary cause of failure is inadequate restorative therapy followed by failure attributable to periodontal reasons [11]. It has been acknowledged for many years that adequate cleaning and obturation of the canal system are essential [12]. In the past decade, however, there has been an increased emphasis on failure caused by orthograde contamination resulting from salivary contamination through an open access preparation or a faulty margin [13–18]. The ultimate decision regarding post placement and choice of restoration is determined by several parameters. Each of these considerations is discussed in detail.

Indications for post placement

The purpose of a post and core is to reinforce the remaining coronal tooth structure and to replace missing coronal tooth structure [19]. Although some studies indicate that a post strengthens a tooth [20,21], most studies suggest that this is not the case [22–24]. The decision regarding post placement should be made based on the position of the tooth in the arch, the amount of coronal remaining tooth structure, and the functional requirements of the tooth.

Molar teeth

Molar teeth receive predominately vertical rather than shear forces. Unless a large percentage of coronal tooth structure is missing, posts are rarely required in endodontically treated molars. More conservative methods of core retention include chamber retention, threaded pins, amalgam pins, and adhesive retention [25]. Nayyar and Walton [26] described the amalcore or coronal-radicular restoration. Amalgam is placed into the chamber and 2 mm into each canal space. This restoration has been successful in both laboratory [27] and clinical studies [26].

The use of threaded pins, both in vertical and horizontal positions [25], has been shown to be quite effective in core retention [28]. There continues to be concern, however, that threaded pins will cause fractures in the endodontically treated tooth. Although there are minimal data to support this allegation, the use of threaded pins has waned in recent years. Today there is a greater emphasis on the adhesively retained core [29,30]. It is clear, however, that the degree of adhesion decreases with thermocycling [31] and with functional loading due to fatigue [32,33]. Until long-term clinical data are available, traditional retention methods should continue to be used in conjunction with the newer adhesive technologies. When a post is required because of lack of adequate remaining coronal tooth structure, it should generally be placed only in the largest canal; that is, the palatal canal in the maxillary molar and the distal canal in the mandibular molar.

Anterior teeth

Because of the shearing forces that act on them, anterior endodontically treated teeth are restored with posts more often than posterior teeth. It is commonly held today that the purpose of the post is to retain the core and to strengthen the remaining coronal tooth structure. Laboratory studies suggest [22–24] that the post does not provide increased fracture resistance to the root and may, in fact, weaken the tooth. When there is no functional or aesthetic requirement for a full-coverage restoration, a post is not indicated. If a full-coverage restoration is chosen, however, the decision to place a post is dictated by the amount of coronal remaining tooth structure after the crown preparation is completed and the functional requirements of the restored tooth. Current research indicates that when an enamel-bonded porcelain veneer is being placed on an endodontically treated tooth, there is no need for a post [34].

Premolar teeth

When restoring an endodontically treated premolar, a decision regarding post placement is made based on the remaining coronal tooth structure, the functional requirements of the tooth, and an evaluation of the forces that act on the tooth. For example, if an endodontically treated premolar has increased functional stresses acting on the crown due to loss of the periodontium and is to serve as an abutment for a removable partial denture, a post may be indicated [35]. Conversely, if a premolar has a relatively short crown and functions more like a small molar, then a post is not indicated.

When a post is indicated for placement in a maxillary premolar, the delicate morphologic anatomy must be considered [36–38]. Post systems that require minimal enlargement and reshaping of the canal space, such as tapered posts, are best suited for maxillary premolars.

Post design

Regarding retention, the active threaded post is most retentive, followed by the passive parallel post; the passive tapered post is least retentive [39–41]. The style of post selected should be based on the amount of retention required for long-term success of the post. For example, if the available post space is short, 5 to 6 mm, a more retentive active post may be indicated. If the available post space is 8 to 9 mm and the canal is not funnel shaped, a tapered post may be a better choice. This is because the available post space is long enough to provide adequate axial retention and it does not require canal enlargement during post space preparation. The design of the post head has a significant effect on the retention of the core material [42,43]. A post should be selected that has a head design appropriate for the chosen core material.

Post length

It is self-evident that greater post length results in greater post retention [40,41]. However, it is important that 4 to 5 mm of gutta percha remain at the apex to minimize leakage [44,45]. When placing a passive post, it should generally be as long as possible while not encroaching on the necessary remaining gutta percha [46].

Post diameter

Although post retention slightly increases with an increase in post diameter [47,48], the ultimate tooth-post combination is weakened because of the increased post diameter [49,50]. The post diameter should be as small as possible while providing the necessary rigidity. It is always important to leave as much tooth structure as possible in all phases of treatment [51].

Surface preparation

Preparation of both the surface of the post and the canal surface can significantly improve post retention [52–56]. Air abrasion and notching of the post have been shown to increase retention. Laboratory data indicate that placing notches or grooves in the surface of the canal also improves post retention [57].

Canal preparation

There are three primary methods of gutta percha removal for post space preparation, including rotary instruments, heat, and solvents. All three methods are effective [44,58–61]. Regardless of which method is used, care must be taken to ensure that the periodontal ligament is not damaged. Injudicious use of rotary instruments, such as Peeso Reamers, may cause a significant temperature increase on the root surface [62,63]. Similarly, a hot instrument may damage the periodontal ligament. Post space preparation may be accomplished at the same appointment in which the canal is obturated or can be delayed for 24 hours or more. The in-vitro data do not indicate that one method is superior to the other [58,60,64–66].

Cement placement

The method used to place cement into the canal before post placement has a significant effect on post retention [67,68]. Spinning the cement into the canal with a Lentulo Spiral has been shown to be the most effective method. Placement of cement with a needle tube is also effective as long as the tip of the needle tube reaches the bottom of the canal space. After the cement is placed into the canal, the post is coated with the cement and placed in the canal.

Luting cements

The importance of the type of cement used for luting posts has been overemphasized in the dental literature. Currently there are five types of cement available for post cementation. In recent years, there has been a great deal of interest in the use of resin cement to bond a post into a prepared canal. Some laboratory studies have shown a significant increase in post retention with resin cement [69–71]. If zinc oxide eugenol is used as the sealer, however, it is not possible to bond successfully to the canal dentin without significantly enlarging the canal [72–77]. When ZOE is used as the sealer, composite luting cement provides no advantage over more traditional cements, and it is significantly more expensive and technique sensitive. Polycarboxylate cement has lower compressive strength and therefore is not a first choice [78]. Glass ionomer has adequate physical properties; however, it is a slow-setting material that requires many hours to achieve adequate strength [79]. Resin-modified glass ionomer cement, as originally formulated, had significant setting expansion. The current generation of resin ionomer cement has overcome this problem and is widely used for post cementation [80]. The most traditional of all cements, zinc phosphate, has adequate physical properties, is inexpensive, and easy to use, and remains an excellent choice for post cementation. When techniques are available to remove canal contaminants in a noninvasive manner, resin cement will probably be the luting agent of choice. However, none of the currently available cements can overcome the problems associated with a poorly engineered post.

Types of posts

Metallic posts

Custom-cast posts

The custom-cast post has a long history of clinical success; however, when it is compared to parallel prefabricated posts, both in vitro [81–84] and in vivo [9,85], its superiority is questionable. There are, however, circumstances in which the custom-cast post is the restoration of choice [19], including the following: (1) When multiple cores are being placed in the same arch. It is more cost effective to prepare multiple post spaces, make an impression, and fabricate the posts in the laboratory. (2) When post and cores are being placed in small teeth, such as mandibular incisors. In this circumstance it is often difficult to retain the core material on the head of the post. (3) When the angle of the core must be changed in relation to the post. Prefabricated posts should not be bent; therefore, the custom-cast post best fulfills this requirement. (4) When an all-ceramic noncore restoration is placed, it is necessary to have a core that approximates the color of natural tooth structure. If a large core is being placed in a high-stress situation, resin composite may not be the material of choice due to the fact that it tends to deform under a load [32,33]. In this circumstance, the post and core can be cast in metal, and porcelain can be fired to the core to simulate the color of natural tooth structure [86]. The core porcelain can then be etched with hydrofluoric acid, and the all-ceramic crown can be bonded to the core.

Prefabricated posts

Passive tapered posts. The essential guideline in post placement is to maintain as much natural pericanal tooth structure as possible. The post that best meets this requirement is the passive tapered post, because it mimics the natural canal shape. However, due to its tapered shape, it provides the least amount of retention [40,41]. When there is adequate canal length for axial retention (8 to 9 mm), and the canal is not funnel shaped, the tapered post is an ideal choice. It is especially useful in the restoration of maxillary premolars, due to their thin, fragile, fluted, tapered root form [36–38].

Passive parallel posts. The parallel post has had a long history of successful use, and it is the post by which all others are measured [9,39–41,85,87]. It provides greater retention than the tapered post; however, a biologic price must be paid for this increase in retention. Because the tapered canal shape must be modified to accept the parallel post, pericanal tooth structure must be removed. A parallel post is therefore recommended when there is a need for increased retention and preparation of the parallel canal space will not jeopardize the root integrity in the apical one third.

Active posts. The term *active* implies that the threads of the post actually engage or screw into the pericanal dentin. Because there are several different designs for active posts, it is difficult to generalize regarding their success. The V-Lock (Brasseler; Savannah, GA) and the Flexipost (Essential Dental Systems; Hackensack, NJ) have performed well in laboratory investigations [72,88–93]. The primary indication for an active post is a circumstance in which there is a need for increased retention in a short canal space that cannot be attained with a passive post.

Non metallic posts

Carbon fiber posts

There has been a significant amount of interest in the development of nonmetallic post systems in recent years. The carbon fiber post (CFP) has been the leader in this category. The disadvantages of the CFP include its black color and its radiolucency, which make it impossible to detect radiographically. The proposed advantages of the CFP are that it can be bonded to and that is possesses a modulus of elasticity (rigidity) similar to dentin [94], making it significantly more flexible than metal posts [95]. The laboratory data indicate, however, that the bond strength of a composite core material to a CFP is, in fact, less than the mechanical retention of composite core material to a metal post [96,97]. It has been reported in one study that bond strength to the CFP can be increased with air abrasion [98], whereas another study reported a decreased bond strength after air abrasion [99]. The issue of post flexibility remains controversial. One group of laboratory studies [100–102] reports increased fracture resistance with the CFP when compared with a metal post, whereas another group of studies [103–106] reports increased fracture resistance with the metal post. The literature does support the notion that the nature of the fractures is more favorable with the CFP than with the metal post [100–105] in all but one study that reported opposite results [107]. Significant concern exists regarding the effect of thermal and cyclic loading on flexural strength of the CFP. A laboratory study reported a significant decrease in flexural strength after cyclic and thermal loading [99]. Regarding post retention, the laboratory data that compare the CFP to metal posts are again equivocal. One study reported increased retention with the CFP [107], another reported equal retention [108], and a third study reported decreased retention with the CFP [94].

The clinical data regarding the success of the CFP are favorable. Fredriksson et al. [109] reported no failures in 236 teeth restored with the CFP in a mean duration of 32 months. Ferrari et al. [110] compared the CFP to the custom-cast post over 4 years. They reported an 11% failure of the custom-cast post, whereas there were no failures of the CFP group due to the post. In another retrospective study, Ferrari et al. [111] reported on the success of CFPs after 1 to 6 years of clinical service in 1304 teeth. They reported a failure rate of only 3.2%. In a retrospective study, Manocci et al. [112] reported a 3-year clinical study comparing the CFP with the custom-cast post. Only one CFP of 226 failed because of post dislodgment, whereas 10 of 194 of the custom-cast posts failed because of root fracture.

Tooth colored posts

A major disadvantage of metal posts and CFPs is their dark color, which adversely affects the natural appearance of the restored tooth. In an effort to overcome this disadvantage, several tooth-colored posts have been developed. These posts include the zirconium-coated CFP, Aesthetic-Post

Plus (Bisco; Schaumburg, IL); the all-zirconium posts, Cosmopost (Ivoclar; Liechtenstein, Germany) and Cerapost (Brasseler); and fiber-reinforced posts, Light-post (Bisco), Luscent Anchor (Dentatus; New York, NY), and Fibrekor Post (Jeneric Pentron; Wallingford, CT).

To conceal the black color of the CFP, one manufacturer covered the CFP with a white zirconium coating, AesthetiPost (Bisco). It has been reported that the physical properties of the coated CFP approximate those of the black CFP [103].

The all-zirconium posts are white and radiopaque. They are quite rigid, with a modulus of elasticity higher than stainless steel [113,114]. The disadvantages of the all-zirconium post include lower fracture resistance than metal posts and an inability to bond to the post [43,114,115]. In addition, if all-zirconium post fractures, removal of the residual post from the root is difficult. Because of the inability to bond to this post, a technique has been described whereby a leucite-reinforced ceramic core material (Empress, Ivoclar) is pressed to the all-zirconium post [116,117]. This technique reportedly provides an adequate bond between the post and the core. Clinical data to support the all-zirconium post are minimal, although there are several short-term clinical studies that show favorable results [113,118,119]. The most recent group of tooth-colored posts to be introduced are the fiber-reinforced composite post [120]. There are minimal data to support the use of these post systems. One laboratory study found the fiber-reinforced resin to be as strong as the CFP and approximately twice as rigid [98].

A final technique that has been advocated for the aesthetic restoration of endodontically treated teeth involves the use of a composite and a woven polyester bondable ribbon to provide a post and core [121]. Laboratory studies that evaluated this technique found it to provide significantly lower fracture resistance than CFPs [103], metal posts [103,122], and custom-cast posts [122].

Minimal data are available that compare these nonmetallic posts. One comparative laboratory study [123] that evaluated fracture resistance found that the Empress (Ivoclar) post and core and the all-zirconium (Cosmopost, Ivoclar) post and core were the weakest. The Vectris (Ivoclar) resin post and composite core and the custom-cast gold post and core demonstrated intermediate fracture resistance. The greatest fracture strength was demonstrated with a titanium post and composite core and zirconium post and composite core. At present, the laboratory data regarding the current generation of nonmetallic posts are equivocal. There is a growing body of clinical data that supports the use of the CFP; however, caution is advised in the use of all nonmetallic post systems when high core strength is required and minimal coronal tooth structure remains.

One of the most difficult restorative treatment situations occurs when a significant amount of internal radicular tooth structure is missing because of caries or iatrogenic removal. In recent years it has been postulated that the missing internal dentin can be replaced with bonded composite, and a post then can be placed in a traditional manner [124]. A laboratory study [125] compared this technique with a custom-cast post and core. The composite-metal post technique provided significantly greater fracture resistance than the custom-cast post and core.

Retention and resistance

The terms *retention* and *resistance* are commonly used interchangeably and incorrectly. Retention is defined as that which resists a tensile or pulling force; resistance is that which opposes any force other than a tensile force. There are three factors that provide retention for a post: post configuration, post length, and the cement. The decision regarding post selection should be made based on the retention requirements of the post. The first factor is post configuration. A post can be active (threaded into the dentin) or passive, and it may be tapered or parallel. Ideally, a post should be selected that requires the least amount of canal enlargement.

A tapered passive post best fulfills this ideal when the canal has not been overenlarged and is of adequate length [40,41]. Adequate length in an anterior tooth is considered to be 8 mm of post space plus 4 to 5 mm of remaining gutta percha at the apex [45]. If more retention is required because of decreased canal length or increased functional requirements (i.e., the tooth is a fixed partial denture abutment), a less tooth-conserving passive parallel post may be indicated. However, as available canal length for post placement decreases, neither type of passive post provides adequate frictional retention. In this circumstance, an active post is required.

The third retention feature is the cement. As discussed in a previous section, the cement provides important retention to the post and core; however, no cement can compensate for a poorly designed post.

The most important consideration in the long-term success of post-retained restorations is the resistance form [87,126]. If the resistance requirements are not met, the probability of failure is high, regardless of the retentiveness of the post. Resistance form is provided by three factors: antirotation, crown bevel, and vertical remaining tooth structure. These three factors work together to provide resistance form, so if one of the features is decreased, long-term success would require that one or both of the remaining two features be increased.

The first feature is antirotation. Every post and core must have antirotation [84,85]. In molars, antirotation is commonly achieved by the square shape of the tooth; however, premolars and anterior teeth are commonly more round. When a round post is placed in the round canal of a round-shaped tooth, antirotation is essential to prevent shear forces from breaking the cement seal. Antirotation can be provided by vertical remaining tooth structure below the margin of the core. In the absence of significant vertical tooth structure, antirotation must be incorporated into the post and core. This task can be accomplished with slots or pins.

The second resistance feature is the crown bevel. The factors that commonly make the placement of a crown bevel impossible are aesthetics and biologic width requirements. With the advent of all-ceramic crowns and ceramometal crowns with porcelain labial margins, a crown bevel is seldom placed on an anterior tooth. For a bevel to provide significant resistance, it must be at least 1.5 mm long [127]. Biologic width requirements generally prevent the placement of this 1.5-mm bevel, especially in anterior teeth.

The third and most important resistance feature is vertical remaining tooth structure above the crown margin. Vertical tooth structure should not be removed and smoothed during preparation for the post and core. It has been shown in a laboratory study that only 2 mm of vertical remaining tooth structure doubles the resistance form [128]. Regarding anterior teeth, it is most important that this vertical remaining tooth structure be on the facial and lingual surfaces. When there is minimal vertical remaining tooth structure to provide adequate resistance form, the long-term success of the post-core-crown combination will not be predictable. Increased vertical tooth height can be gained by crown-lengthening surgery; however, in anterior teeth, single-tooth crown lengthening often results in unacceptable aesthetics. The treatment of choice, before placement of the restoration, is orthodontic eruption [129].

Core materials

Prefabricated posts are used more commonly than custom-cast posts, so it is important to understand the properties of the available core materials to select the appropriate material for a given situation. Five currently available core materials are discussed.

The custom-cast post and core has a long history of successful use. It provides high strength, and there is no concern that the core may delaminate from the post. The fabrication of the custom-cast post and core is expensive and time consuming, however.

Amalgam also has a long history of success. Its strength has been confirmed in laboratory studies in both static and dynamic loading [32, 33,81,130]. Amalgam has several disadvantages, however. The dark color of amalgam has the potential to lower the value of all-ceramic restorations and to cause a gray halo at the gingival margin. Additionally, it is not possible to bond to set amalgam. Its low early strength requires a 15–20-minute wait before core preparation, even when a fast-set spherical alloy is used. It is messy to prepare and can result in irreversible staining of the marginal gingiva during preparation. Even in the face of these disadvantages due to its high ultimate strength, amalgam with a prefabricated post, and the custom cast post are the materials of choice in a high stress situation.

Conventional glass ionomer has several advantages, including fluoride release and ease of manipulation; however, these advantages are outweighed by the major disadvantage of low fracture toughness, which reflects a material's ability to resist crack propagation [78]. In an attempt to increase the fracture toughness, silver reinforcement has been added to conventional glass ionomer. Unfortunately, silver-reinforced glass ionomer also has a low fracture toughness [131]. These materials should therefore only be used in posterior teeth in which more than 50% of the coronal tooth structure remains.

The newest available core material is resin-modified glass ionomer. It is easy to manipulate; however, its physical properties lie between those of conventional glass ionomer and composite [132]. In high-stress situations, therefore, it is not the material of choice.

Composite resin has a long history of use as a core material due to its ease of manipulation. It is available in light-cured, autopolymerized, and dual-cured formulations, and it comes in tooth colors and contrast colors for posterior use. A major advantage of composite is its ability to be bonded to tooth structure and then to serve as a substrate to which a ceramic crown can be bonded. Laboratory studies have confirmed adequate fracture toughness [131] and compressive strength in a static load test [81,83]. However, composite has not performed as successfully in dynamic load tests that are performed in a chewing machine [32,33,130]. Under this repeated load, the composite appears to undergo a plastic deformation that may lead to core failure. Also, composite is not dimensionally stable in a wet environment [133]. As it absorbs water, the core expands and as the composite dries out, the core shrinks.

Composite resin is the most user-friendly of all the core materials, so it is the core material of choice when there is remaining coronal tooth structure to help support the core. However, when high strength is required and there is minimal remaining coronal tooth structure, composite is not the material of choice.

Definitive restorations

In posterior teeth there are several choices for definitive restorations, including amalgam, direct composite, indirect composite, bonded ceramic, and cast metal. All of these materials may be used for partial or complete cuspal coverage and intracoronally. Because laboratory data [6] indicate that a conservative access preparation has minimal effect on the fracture resistance, some authors question the need for cuspal coverage restorations in all endodontically treated posterior teeth. In support of this philosophy, there are many laboratory studies that demonstrate the strengthening effect of a bonded composite restoration [134–139]. Additionally, a retrospective clinical study [140] reported a high success rate when restoring endodontically treated posterior teeth with intracoronal direct placement composite restorations; however, there is some question regarding the long-term strengthening effect of the composite restoration. It is known that the strength of dentin bonding decreases over time [141] because of load fatigue [142] and thermocycling [31]. In addition, it is postulated that a portion of the sensory feedback mechanism is lost when the neurovascular pulpal tissue is removed during root canal therapy [7]. Clinically, this means that a person can inadvertently bite with significantly more force on an endodontically treated tooth than on a vital tooth due to the impaired sensory feedback mechanism. Both laboratory [143] and retrospective clinical studies [85] have demonstrated that the essential element in the long-term success of a posterior endodontically treated tooth is the placement of a cuspal coverage restoration. If conservative is defined as a restoration that has the highest probability of conserving the tooth in function for the remainder of the life of the patient, then the cuspal coverage is the most conservative choice. This type of restoration can be accomplished with a wide variety of materials as long as the restoration is well engineered.

Laboratory studies [22,24,82] indicate that the fracture resistance of an endodontically treated anterior tooth with conservative endodontic access is approximately equal to that of a vital tooth. For this reason, when a significant amount of tooth structure remains and there is no plan to place a crown, there is no need to place a post. A simple bonded composite is the restoration of choice.

When at least 50% of the coronal tooth structure, including enamel, remains intact, an enamel bonded porcelain veneer may be the restoration of choice. A laboratory study confirms the efficacy of the porcelain veneer in this circumstance [144] and also shows that a post is not indicated [34]. When the decision is made to place a crown for aesthetic or functional reasons, however, a post may be indicated.

The decision to place a post in an anterior tooth is made based on the amount of remaining coronal tooth structure after the crown preparation and the functional requirements of the tooth. Because the maxillary lateral incisors and the mandibular incisors are smaller teeth, a post is commonly indicated before crown placement. In maxillary central incisors and canine teeth, however, the decision should be made after crown preparation. If the dentist believes there is adequate remaining tooth structure to provide adequate resistance to fracture, a bonded composite is placed in the access preparation. If, in the judgment of the dentist, there is insufficient remaining coronal tooth structure to resist the functional or parafunctional forces, a post is placed.

Summary

It has been the purpose of this article to provide a rationale for the restoration of endodontically treated teeth. Treatment recommendations have been made in the areas of post design, placement technique, cements, core materials, and definitive restorations, based on a review of the clinical and laboratory data.

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